Technical Support Documents

Summary of State Measures

State regulatory actions under way:

There are several State initiated control measures under consideration by the State of Tennessee, and the Tennessee Air Pollution Control Board, which may accomplish large reductions in emissions. These may include proposed state regulatory or administrative decisions that would mandate or require actions by parties outside of state government. Some of these recommendations would necessitate changes to rules and regulations issued by the state Air Pollution Control (APC) Board, and some recommendations would require legislative revisions to current statutory authority. Other regulatory and administrative decisions could be made using current statutory authority.

Researchers at the University of Tennessee have evaluated a number of potential control measures. The control measures identified as the most effective for reducing NOx and VOC emissions include some of the following: more stringent vehicle inspection and maintenance programs; controls on point sources that emit more than 50 tons per year of NOx; statewide options for reducing engine idling and smoking; lower interstate speed limits; and others. These control measures are discussed in more detail below.

Inspection and maintenance (I&M) for light-duty vehicles

Currently, five Middle Tennessee counties operate a vehicle inspection and maintenance program for vehicles up to 8,500 GVWR (gross vehicle weight rating), and the city of Memphis tests vehicles up to 26,000 GVWR. These vehicles must pass emissions testing prior to vehicle registration renewal. Inspection and maintenance programs provide significant reductions of NOx and VOC. The current APC rules at Paragraph 1200-3-29-.03(1) provide the authority to operate an I&M program in any county designated by the APC Board. Legislative amendments to *Tennessee Code Annotated*, Section 55-4-30, are necessary and are underway to provide for registration renewal enforcement of the I&M testing requirement in the counties designated by the APC Board or for those counties that choose to implement an I&M program.

Reasonably Available Control Technology (RACT) rule for NOx

The APC Division has proposed a statewide rule that would require reasonably available control technology to reduce NOx emissions from stationary sources that emit 50 or more tons per year of NOx. The APC Board will act on this rule and other regulations for the 8-hour ambient ozone control strategy as a package. Ultimately, the board will decide if the NOx RACT rule should be statewide, limited to the counties within a metropolitan statistical area (MSA), to EAC counties, or just to those counties designated as nonattainment for the 8-hour ozone standard.

Reduce engine idling

According to the U.S. Environmental Protection Agency, a typical heavy-duty truck or bus can burn approximately one gallon of diesel fuel for each hour it idles, thereby generating significant amounts of pollution, wasting fuel and causing needless engine wear. Diesel exhaust contributes to ozone formation and haze, and idling trucks and buses are often an unnecessary source of harmful air pollution.

Idling restrictions would reduce driver and passenger exposure to elevated concentrations of air pollutants. This is especially important to our children who are exposed daily to harmful diesel exhaust from school buses. Also, any reductions of NOx and VOC are beneficial and would improve air quality in the immediate vicinity. This could be significant in areas with large truck stops where many vehicles idle for extended periods. Additionally, there would be a fuel savings by not idling for extended periods. The Board would need to consider exemptions and reasonably available anti-idling alternatives for circumstances where power sources are needed for heating, cooling and other important functions.

Anti-tampering and anti-smoking rules for vehicles

The state has had lengthy discussions with EPA on the implementation and merits of an anti-tampering program in areas of the state where an IM program does not exist. Part of the problem the Air Pollution Control Agency has had regarding this measure is the air pollution emission reduction credit that EPA will approve for operating a state anti-tampering enforcement program. However, the state and the APC Board are concerned about tampering of emissions control equipment by automobile repair facilities and dealerships. The currently proposed rule also contains a provision for certification requirements for vehicles offered for sale, rent or lease. Legislative amendments would be necessary to address certification requirements for vehicles being sold in Tennessee.

Some local air pollution control programs in Tennessee, such as the Metropolitan Nashville-Davidson County program, prohibit smoking vehicles. The State has drafted regulations to prohibit excessive visible emissions from motor vehicles.

Reduce speed limits on rural interstate highways

Researchers at the University of Tennessee-Knoxville have determined that the highest emissions of NOx from on-road mobile sources occur at high vehicle speeds. This is especially true for heavy-duty diesel vehicles, which typically contribute about 60 percent of the NOx emissions on Tennessee interstates. Lowering the speed limit for heavy-duty diesel trucks to 55 mph on rural interstates could significantly reduce NOx emissions.

Setting speed limits is an administrative function of state government. The APC Board has no regulatory authority over setting speed limits for automobiles or trucks; however, the Board recognizes the air quality benefits of such a restriction on truck speeds. As evidenced by recent actions in the State of Texas, lowering speed limits for air quality control purposes can result in significant opposition by the general public. It is unlikely that the state will pursue a lowering of speed limits unless it can be shown that it is the last viable measure to bring an area into attainment.

Considerations:

- One option is to consider lowering the speed limit on those days where high ozone levels are forecasted or during ozone season.
- Safety and enforcement concerns have been expressed about having different speed limits for large trucks than for other vehicles.
- The Tennessee Trucking Association testified before the APC Board that it would support lowering the speed limit for all vehicles.

- Lower speed limits would probably increase fuel economy and improve safety.
- The costs of lowering the speed limit are difficult to assess; however, there would be costs to state government for signage and costs to citizens for extra travel time.

Develop a diesel retrofit program

Controlling emissions from heavy-duty diesel engines will achieve significant reductions in NOx and fine particle pollution. New federal standards for diesel fuel and diesel engines will have a significant role in reducing emissions from new on-road diesel engines; however, these new standards will not have an impact on existing heavy-duty diesel engines. Because diesel engines typically have a useful life of 20 or more years, additional measures to reduce exhaust emissions from existing on-road and off-road diesel engines may yield significant pollution reduction benefits.

The state could lead an effort to establish a program to encourage and assist local and state agencies and private companies to upgrade or retrofit diesel engines that do not meet 2007 federal engine standards. This program should especially target—

- School buses
- Mass transit buses
- Heavy-duty diesel engines in state fleets (on- and off-road)
- Heavy-duty diesel engines in local government fleets (on- and off-road)

First priority should be given to those vehicles in designated nonattainment areas and those vehicles whose emissions may directly affect sensitive populations, such as school children. In this regard, the state of Tennessee could take a leadership role in assisting local government efforts to retrofit (or perhaps replace) hundreds of diesel school buses. Providing cleaner transit protects the health and safety of our children. Likewise, using cleaner fuels and technologies in mass transit system buses will help improve air quality in urban areas.

Considerations:

- Although effective at reducing diesel exhaust emissions, retrofit technology is expensive. For example, current cost estimates for installing diesel particulate filters vary from $5,000 to $8,000 per unit, depending on a variety of factors (e.g., age and type of engine).
- Dedicated funding is needed to encourage fleet owners to install retrofit technology. The State is continuing to look for diesel retrofit funding opportunities, such as grant programs. Another initiative is an “Adopt-A-School-Bus” program, whereby local school systems partner with local businesses and other interests to generate private donations to pay for school bus retrofits or replacements.

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SESARM

Early Action Compact Ozone Modeling Analysis for the State of Tennessee and Adjacent Areas of Arkansas and Mississippi

Technical Support Document

March 30, 2004

04-012

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SESARM

Early Action Compact Ozone Modeling Analysis for the State of Tennessee and Adjacent Areas of Arkansas and Mississippi

Technical Support Document

March 30, 2004

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Executive Summary

This report summarizes the methods and results of a photochemical modeling analysis designed and conducted to support the attainment and maintenance of the 8-hour ozone standard for five areas in Tennessee (and several adjacent counties in Arkansas, Mississippi, and Georgia) as part of an Early Action Compact (EAC). The Early Action Compact agreements (effective December 31, 2002) provide for planning and implementation of voluntary measures to ensure future attainment/maintenance of the 8-hour ozone standard. Under these compacts, local, state, and EPA officials agreed to work cooperatively to ensure clean air and a designation of attainment.

The five areas with active EAC agreements include:

- **Memphis EAC area:** Shelby, Tipton, and Fayette Counties (Tennessee), Crittenden County (Arkansas), and DeSoto County (Mississippi).
- **Nashville EAC area:** Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties.
- **Knoxville EAC area:** Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties.
- **Chattanooga EAC area:** Hamilton, Marion, and Meigs Counties (Tennessee), and Walker and Catoosa Counties (Georgia).
- **Tri-Cities EAC area:** Carter, Hawkins, Sullivan, Unicoi, and Washington Counties.

The National Ambient Air Quality Standard (NAAQS) for 8-hour ozone requires the three-year average of each year's fourth highest 8-hour ozone concentration (the 8-hour design value) for each monitoring site in a given area to be less than or equal to 84 parts per billion (ppb). Ozone concentrations and calculated 8-hour design values for monitors within each of the EAC areas have in recent years approached or exceeded the 8-hour standard. Specifically, the 2000–2002 and 2001–2003 design values are listed in Table ES-1.

Table ES-1.
Observation-Based 8-Hour Ozone Design Values (ppb) for the EAC Areas: 2000–2002 and 2001–2003

EAC Area	2000–2002	2001–2003
Memphis	94	92
Nashville	88	86
Knoxville	98	92
Chattanooga	93	86
Tri-Cities	92	75

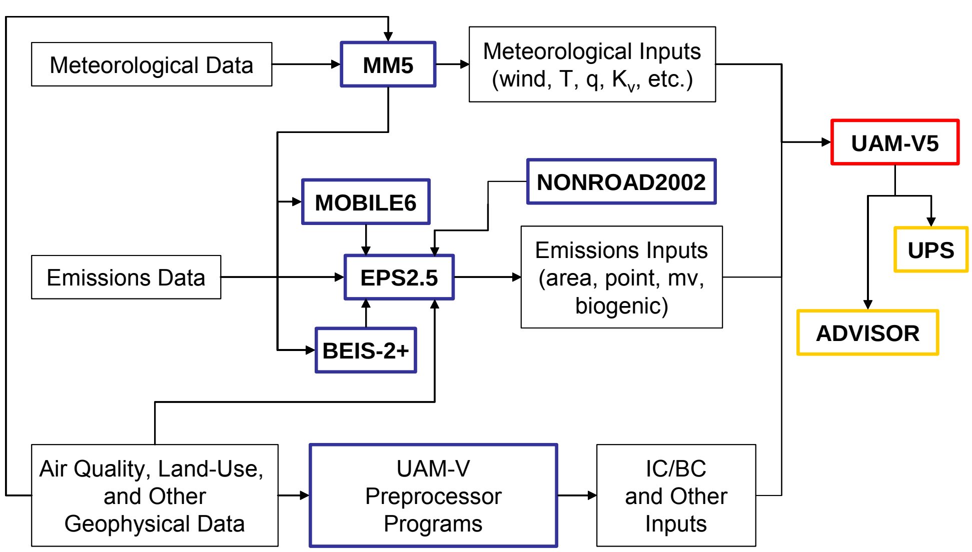
The EAC agreements require that photochemical modeling be used to demonstrate attainment of the 8-hour ozone NAAQS by 2007 and maintenance of the NAAQS through 2012. Consequently, a comprehensive modeling analysis and attainment and maintenance demonstration was conducted to support the EAC modeling effort. The primary objectives of the modeling analysis are to provide (1) an improved understanding of the ozone formation/transport mechanisms that influence ozone levels within each EAC region, (2) a reliable projection of future-ozone concentrations, and (3) a platform for assessing the effectiveness of emission-reduction measures on future ozone air quality in the EAC areas. The modeling study was designed in accordance with draft EPA guidance (EPA, 1999) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes.

The EAC modeling study utilized the databases and modeling tools developed for the Arkansas-Mississippi-Tennessee Ozone Study (ATMOS). Numerous enhancements were made to the overall ATMOS modeling analysis and detailed model input databases to ensure a comprehensive and technically up-to-date analysis of 8-hour ozone issues for the areas of interest. These included the addition of two multi-day modeling episodes to complement the ATMOS modeling episode period and to ensure a sufficient number and range of days for application of the modeled attainment test procedures, as well as full update of the modeling emission inventories to include the latest National Emission Inventory (NEI) data (for 1999), updated state-specific emissions data, and the use of the latest EPA tools for estimating on-road mobile and non-road emissions.

Overview of the Photochemical Modeling System

The primary modeling tools selected used for this study include: the variable-grid Urban Airshed Model, Version 1.5 (UAM-V5), a regional- and urban-scale, nested-grid photochemical model; the Emission Preprocessor System (EPS2.5), for preparation of model ready emission inventories; the Biogenic Emission Inventory System with high-resolution land-use and crop data (BEIS-2+), for estimating biogenic emissions; the MOBILE6.2 model, for estimating motor-vehicle emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The UAM-V5 modeling system outputs were summarized and displayed using the UAM-V Postprocessing System (UPS) and the ATMOS ACCESS Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR). Figure ES-1 provides an overview of the ATMOS EAC modeling system, including key input data requirements, UAM-V5 input files, and interactions among the modeling system components.

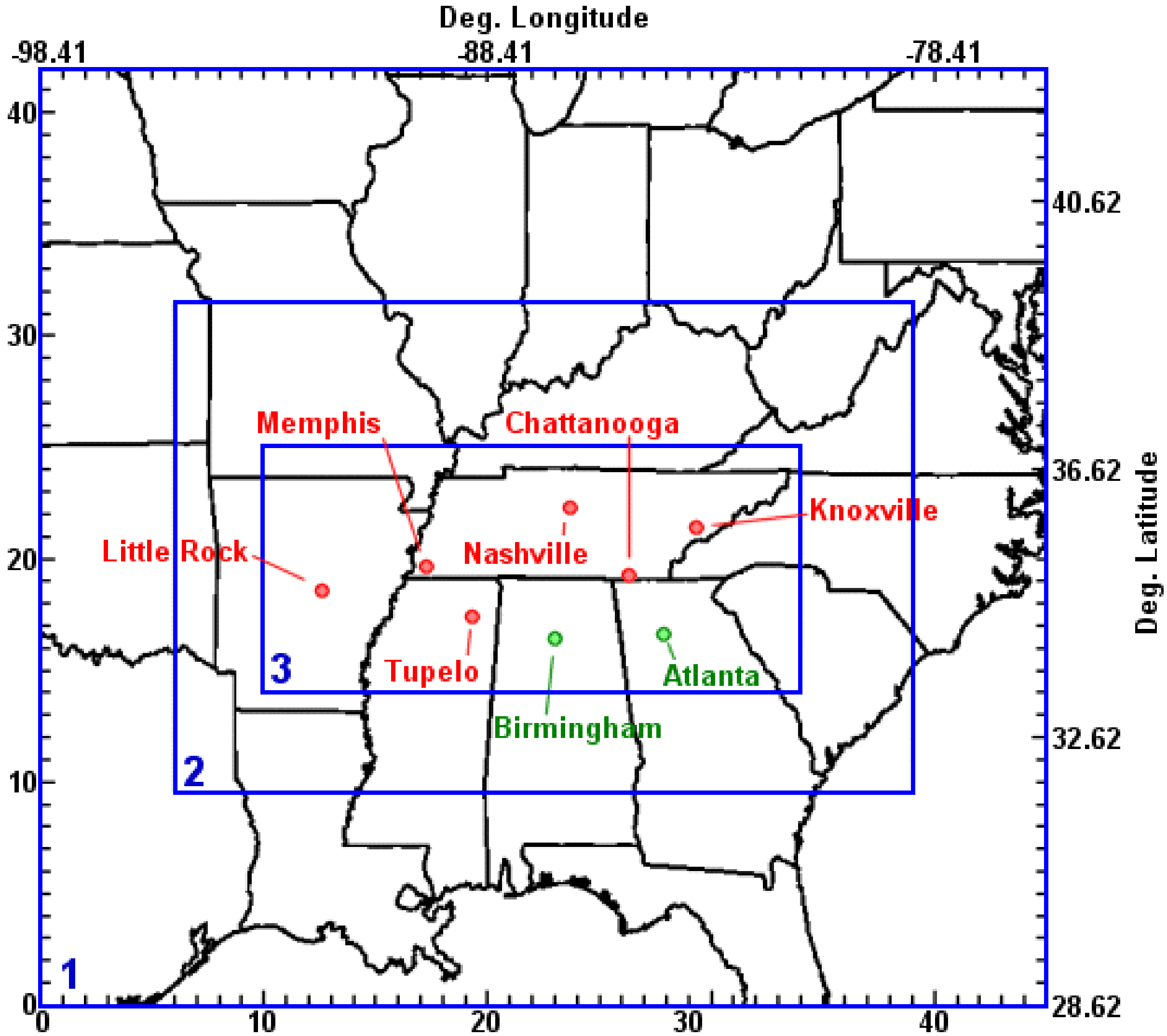
Figure ES-1.
Schematic Diagram of the ATMOS EAC Photochemical Modeling System



Modeling Domain

The modeling domain for application of the UAM-V5 modeling system for the ATMOS EAC modeling analysis is the same as the original ATMOS domain and was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the areas of interest. It consists of an outer grid with 36-km horizontal resolution that encompasses the southeastern U.S., an intermediate grid with 12-km resolution over the mid-south, and a 4-km inner grid over Tennessee and portions of Arkansas, Mississippi, and other neighboring states. The domain is further defined by eleven vertical layers with interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters above ground level. The domain is illustrated in Figure ES-2.

Figure ES-2.
UAM-V Modeling Domain for the ATMOS Study



Conceptual Model

Developing a conceptual model for 8-hour ozone is an important component of any 8-hour ozone modeling analysis. The conceptual model sets the stage for understanding the physical and chemical factors that influence ozone concentrations within the area of interest and that potentially result in exceedances of the 8-hour ozone standard. The conceptual model also provides the basis for identifying the type and frequency of occurrence of different types of 8-hour ozone episodes and thus for the selection of modeling episode periods or key days for analysis of the modeling results. Finally, the conceptual model serves to provide focus to the interpretation of the modeling results and the development of effective attainment strategies.

Examination of 8-hour ozone data for the EAC areas for the 1996-2002 analysis period shows that

- All areas had some exceedance days, and the Memphis, Nashville, and Knoxville area had 90th percentile values greater than 84 ppb.
- The Knoxville area experienced the greatest number of exceedance days (nearly as many as Atlanta).
- July and August are the peak ozone months for most areas, although Nashville and the Tri-Cities areas had more exceedance in June than in July.
- The years 1997, 1998 and 1999 were high ozone years for most of the areas; in contrast, ozone concentrations tended to be lowest for 2001.
- Same-day correlations among the areas of interest suggest that 8-hour ozone concentrations are subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions.

Ozone episodes within each of the EAC areas occur under a variety of regional-scale meteorological conditions and prevailing wind directions. The regional-scale patterns, in turn, influence the development of local ozone-conducive meteorological conditions.

A more detailed analysis of the observed ozone data and meteorological conditions for each EAC area allowed us to tailor the conceptual description to each area. Some general key findings include:

- Yesterday's maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, and lower wind speeds (compared to lower ozone concentration days).
- The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships.
- Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions and that there are multiple pathways to high ozone for each of the areas.

Episode Selection

Episode selection for the ATMOS EAC modeling/analysis was based on a review of historical meteorological and air quality data with emphasis on representing typical ozone exceedance events in the areas of interest. The episode selection was conducted in stages. First, in 2000, a primary multi-day simulation period was selected for the ATMOS modeling. This period was selected to optimize the representation of typical 8-hour ozone exceedance conditions and concentration levels for all of the areas of interest (which, for ATMOS, included all of the EAC areas with the exception of the Tri-Cities EAC area). A second multi-day simulation period was added in 2003, to enhance the robustness of the EAC modeling by including additional days and types of exceedance conditions. This episode was specifically selected to complement the first ATMOS simulation period in terms of representing different key meteorological conditions and providing additional exceedance days for certain areas. Finally, a third multi-day simulation period was added in 2004, as modeling databases from the State of Arkansas became available for use in the ATMOS study. This third simulation period includes additional exceedance days for all of the areas of interest and some variation on the exceedance meteorological conditions for certain of the areas. It provides important additional exceedance days for the Tri-Cities area.

Overall, the primary objective of the episode selection was to identify and assemble suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the ATMOS EAC areas of interest. Important considerations in selecting (and adding to) the episodes include (1) representing the range of meteorological conditions that accompany ozone exceedances, (2) representing the ozone concentration levels that characterize the nonattainment problem, and (3) accounting for the frequency of occurrence of the exceedance meteorological regimes.

The three ATMOS EAC episodes are 29 August–9 September 1999, 16–22 June 2001, and 4–10 July 2002. The three episodes selected for this study each include two start-up days and one clean out day. The length of each episode was designed to capture the entire high ozone cycle for each area of interest as influenced by the synoptic and mesoscale meteorological conditions. The episodes also include both weekdays and weekend days. Area-specific observations are summarized below. The three modeling episodes include:

- Ten exceedance days that represent two of the three key exceedance meteorological regimes as well as several other high ozone regimes for Memphis, with a range of 8-hour ozone exceedance concentrations from 86 to 106 ppb and an average 8-hour ozone exceedance concentration of 94 ppb.
- Twelve exceedance days that represent four of the five key exceedance meteorological regimes for Nashville, with a range of 8-hour ozone exceedance concentrations from 85 to 110 ppb and an average 8-hour ozone exceedance concentration of 98 ppb.
- Eighteen exceedance days that represent four of the five key exceedance meteorological regimes as well as several other high ozone regimes for Knoxville, with a range of 8-hour ozone exceedance concentrations from 86 to 104 ppb and an average 8-hour ozone exceedance concentration of 95 ppb.
- Eleven exceedance days that represent two of the three key exceedance meteorological regimes for Chattanooga, with a range of 8-hour ozone exceedance concentrations from 85 to 107 ppb and an average 8-hour ozone exceedance concentration of 93 ppb.
- Five exceedance days for the Tri-Cities area with range of 8-hour ozone exceedance concentrations from 87 to 101 ppb and an average 8-hour ozone exceedance concentration of 92 ppb.

Meteorological Modeling

Meteorological inputs were prepared for the ATMOS UAM-V5 application using the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5). Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, and a detailed treatment of the planetary boundary layer.

MM5 was applied for each simulation period and the results were evaluated using graphical and statistical analysis. Comparison with the observed data was used to examine the model's ability to represent key meteorological features such as the wind speeds as directions and site-specific temperatures. In summary, the MM5 results for the three modeling episode periods represent the regional-scale airflow patterns and the temperature and moisture characteristics of the episodes. Wind speeds (especially under light wind conditions) to tend to be overestimated, and the MM5-derived vertical mixing profiles, while realistic, do not always agree with observation-based mixing height estimates.

Emission Inventory Preparation

Base-year, current-year (2001), and future-year (2007 and 2012) emissions were prepared using the final version of the EPA NEI 1999 emission inventory, state-specific emissions data and vehicle miles traveled (VMT) estimates, and Bureau of Economic Analysis (BEA) emissions projection factors. The data were processed using the latest version of the modeling tools discussed above and listed/outlined in Figure ES-1. Total emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOC) for each EAC area are displayed and compared for the current and future years in Figure ES-3.

Figure ES-3a.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

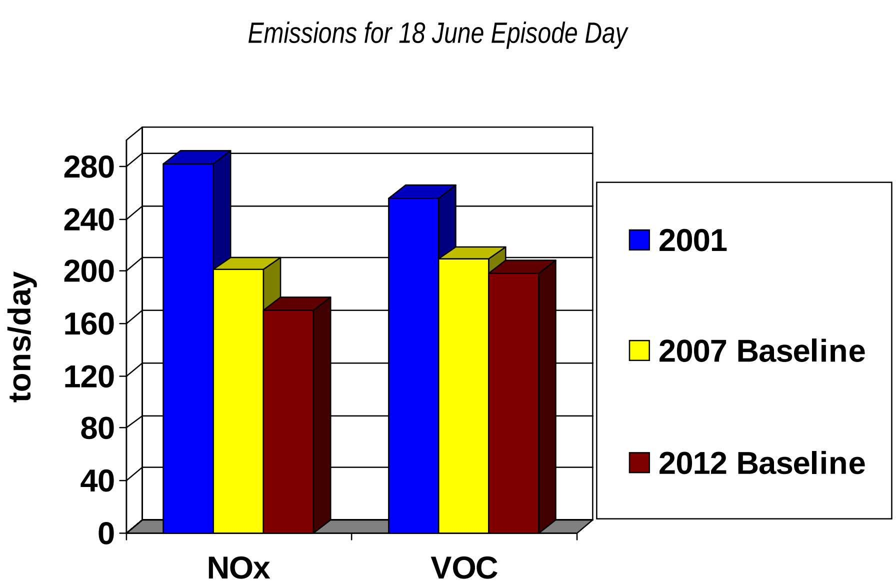


Figure ES-3b.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

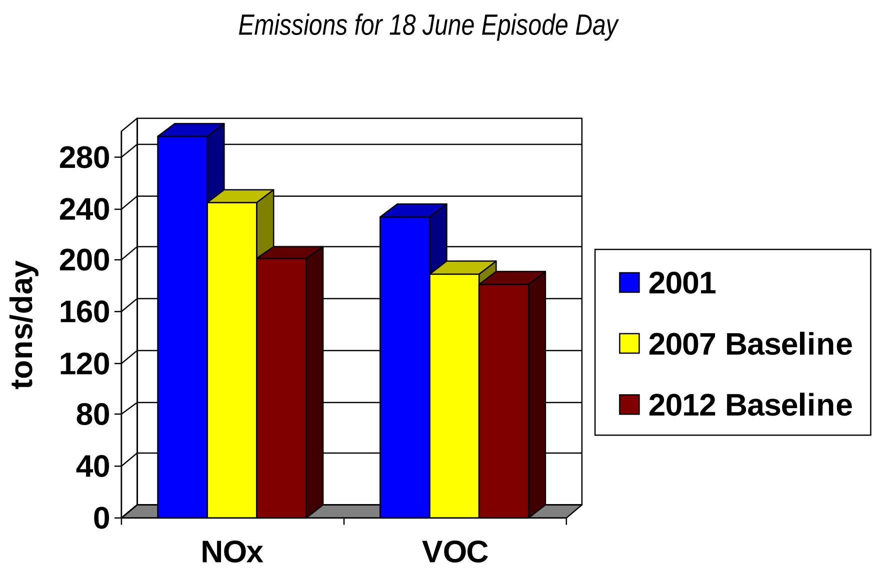


Figure ES-3c.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

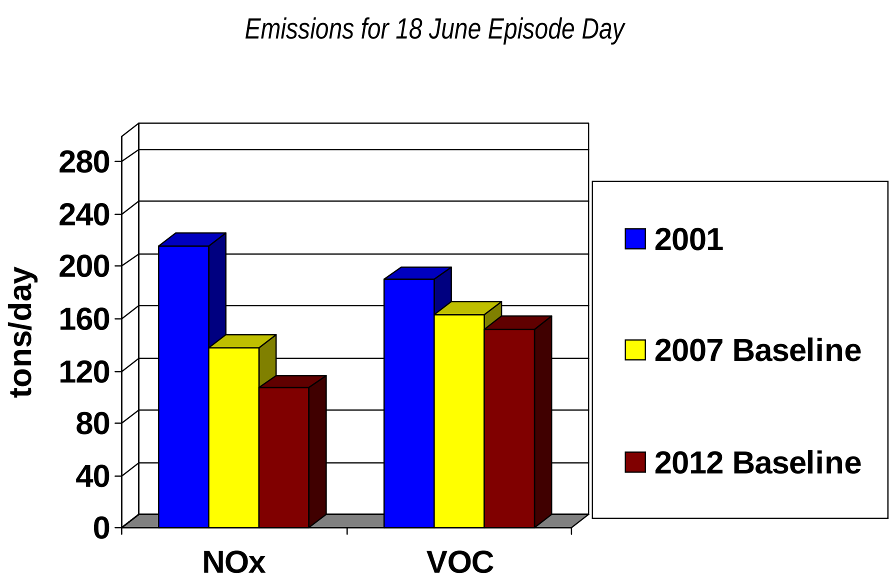


Figure ES-3d.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

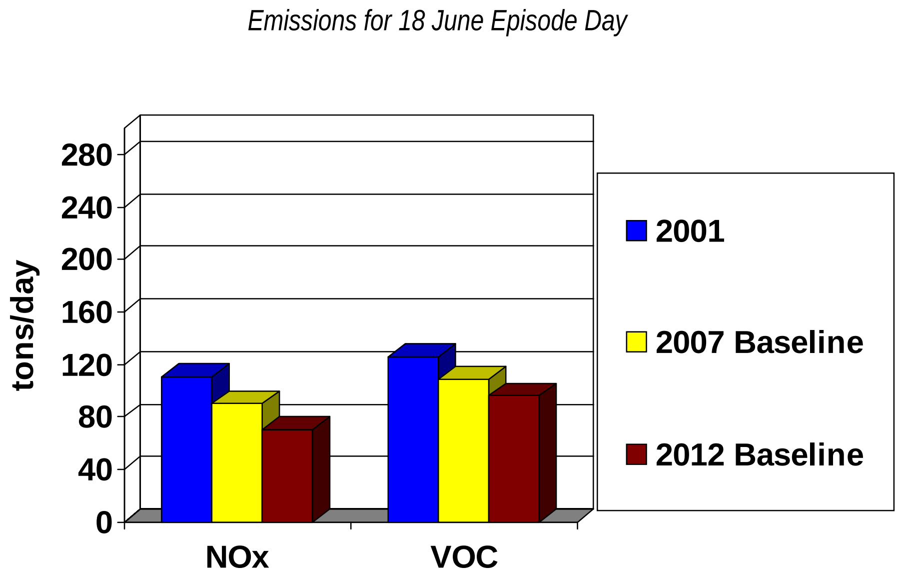
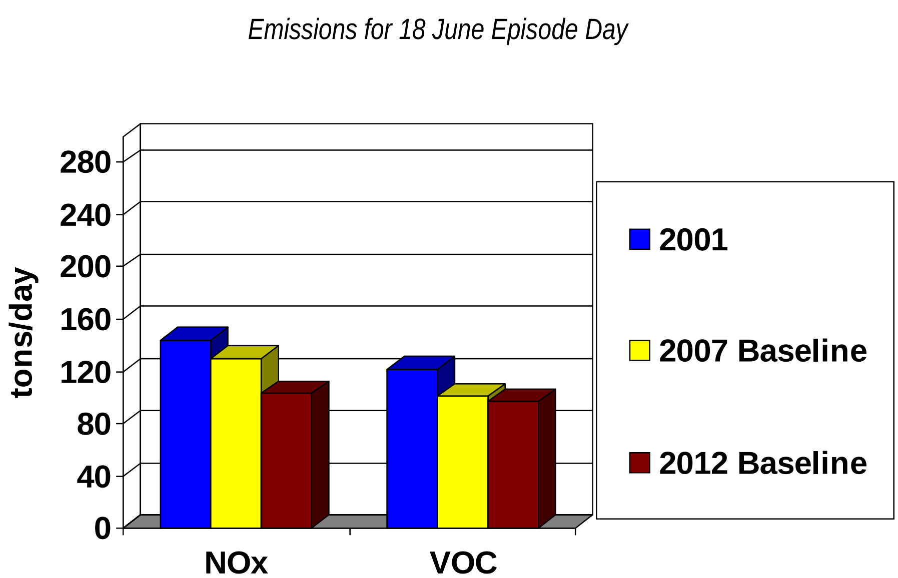


Figure ES-3e.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area



Model Performance Evaluation

The base-case modeling analysis for each simulation period consisted of an initial simulation, a series of diagnostic and sensitivity simulations, a final base-case simulation, and graphical and statistical analysis of each set of modeling results, including comparison with observed air quality data. We first focused on 1-hour ozone concentration patterns and statistical measures for the full modeling domain and each subdomain. This provided perspective on regional-scale model performance and whether the model is able to capture day-to-day variability in the concentration patterns and values. We then examined the hourly concentrations for each area and site of interest. It is important that the model capture the hourly variations and 1-hour peaks in order to reliably represent the 8-hour average values. We then examined the performance of the model in representing 8-hour ozone concentrations throughout the domain and for each area and site of interest.

Based on the graphical and statistical analysis, acceptable model performance is achieved for all three episode periods. Modeling results for all three episode combined are used in the attainment test to calculate the relative reduction factors and estimated future-year design values. Table ES-2 summarizes model performance for each site using all three of the simulations periods and the site-specific unpaired accuracy metric. For the most part, the metrics fall squarely within the EPA suggested bounds (of $\pm$ 20 percent) for acceptable performance. Overall the simulations tend to underestimate ozone within the Knoxville area, especially for the higher elevation sites located in the Great Smoky Mountains National Park. For the other areas, there is both some over- and underestimation of the 8-hour ozone values. These results indicate that the combined use of days provides an excellent basis for application of the attainment test procedures.

Table ES-2.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; All Episodes Combined, Excluding Startup Days

Site	Site-specific Average Accuracy Of The 8-Hour Ozone Peak (%)	Site-specific Average Accuracy of the 8-Hour Ozone Peak in the Vicinity of the Monitoring Site (%)
Memphis EAC		
DeSoto County, MS	-1.0	4.0
Edmond Orgill Park, TN	-7.9	-4.2
Frayser, TN	-6.1	2.1
Marion, AR	-4.6	2.9
Nashville EAC		
Cedars of Lebanon State Park	6.6	10.4
Cottontown Wright's Farm, TN	-8.8	-3.0
Dickson County, TN	-9.3	-5.3
East Nashville Health Center, TN	4.1	21.4
Fairview, TN	0.4	4.9
Percy Priest Dam, TN	2.8	16.2
Rockland Road, TN	7.0	11.8
Rutherford County, TN	-8.4	-5.8
Knoxville EAC		
Anderson County, TN	-2.3	3.0
Cades Cove, TN	8.9	11.9
Clingman's Dome, TN	-14.5	-11.8
Cove Mountain, TN	-16.4	-13.2
East Knox, TN	-4.6	0.1
Jefferson County, TN	-2.6	2.9
Look Rock (1), TN	-10.6	-5.8
Look Rock (2), TN	-21.1	-16.6
Spring Hill, TN	-17.7	-4.7
Chattanooga EAC		
Chattanooga VAAP, TN	-2.5	6.5
Meigs County, TN	-11.0	-3.9
Sequoyah, TN	-2.1	4.9
Tri-Cities EAC		
Kingsport, TN	-3.1	13.6
Sullivan County, TN	-3.9	4.3

Future-Year Modeling

The ATMOS EAC future-year modeling exercises include the application of the modeling system for a current-year (2001) and two future years (2007 and 2012). The use of a "current" year allowed us to combine the results from the three different episode period in applying the EPA modeled attainment test procedures, despite the different base years. In addition to the current- and future-year baseline simulations, several emissions sensitivity and control-strategy simulations were conducted for the 2007 future year. The UAM-V Oxidant and Precursor Tagging Methodology (OPTM) was used to assess the contribution to simulated ozone in the EAC areas from various source categories and source regions. Several control strategy simulations were conducted to quantify the effects of specific emission-reduction measures and packages of measures on the simulated future-year ozone concentrations. The final control-strategy simulation (AS-4) includes the final EAC attainment strategy measures for each area.

Attainment Demonstration

The procedures outlined in the draft guidance document on using models and other analyses to demonstrate future attainment of the proposed 8-hour ozone standard (EPA, 1999) were adapted for the ATMOS modeling domain and simulation periods and applied using the results from the 2007 attainment strategy simulation.

The attainment demonstration for each EAC area consisted of the modeled attainment test, the screening test, and additional corroborative analyses. For ATMOS, we offer a variety of weight-of-evidence analyses that are designed to improve our understanding and interpretation of the modeled attainment test results, and to explore the effects of the various assumptions that are employed in the application of the photochemical model and the attainment test procedures. Our goal here is to make the best possible use of the modeling results and the observed data to assign a level of confidence to the outcome of the modeled attainment test.

As part of the weight of evidence analysis, we explore the use of a meteorologically adjusted design value in the application of the attainment test. The design value is an important part of the modeled attainment test, in which future design values are estimated. For ATMOS, the modeled attainment test primarily uses, as its basis, the observation-based design value for the three-year period spanning the current model year. This value is expected to represent the current period in the same way the modeled simulation periods are expected to represent typical or frequently occurring meteorological conditions. Thus it is important that the base or current design value is representative of typical meteorological conditions. Given the form of the design value metric, however, year-to-year variations in meteorology and especially unusually persistent meteorological conditions during one or more of the years comprising a design value cycle can lead to a design value that is not representative of typical conditions.

While the 8-hour ozone design value is formulated in part to accommodate year-to-year variations in meteorological conditions, recent variations in the design values for the several of the ATMOS EAC areas have indicated that the metric may not be stable when weather conditions (either ozone conducive or not) persist over the region for large portions of the ozone season. In developing “meteorologically adjusted” design values for each area, our objective was to create a metric similar to the 8-hour design value but less sensitive to yearly meteorological variation.

Summary Attainment Demonstration for Memphis

The attainment and screening tests and additional corroborative analyses indicate that the Memphis EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

Three of the four monitoring sites in the Memphis area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. One site, the Marion site in Crittenden County, AR, has a future-year estimated design value (EDV) that is greater than the 84 ppb standard. The 2007 EDV for this site is 88 ppb if the 2000-2002 design value is used, 86 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. The 2000-2002 design value is the highest recorded in recent years. Based on the values for the other years as well as the indications from the meteorological adjustment, use of the 2000-2002 design value likely represents a worst case for Memphis for 2007. Thus, the modeling results together with the corroborative analysis indicate that Memphis will be in attainment of the 8-hour ozone standard by 2007.

Summary Attainment Demonstration for Nashville

The attainment and screening tests and additional corroborative analyses indicate that the Nashville EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

All of the monitoring sites in the Nashville area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. The areawide 2007 EDV for this site is 82 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. Use of a meteorologically adjusted DV that is higher than observed supports a finding of modeled attainment. Thus, the modeling results together with the corroborative analysis indicate that Nashville will be solidly in attainment of the 8-hour ozone standard by 2007.

Summary Attainment Demonstration for Knoxville

The modeled attainment test indicates that the Knoxville EAC area will likely not achieve attainment of the 8-hour ozone standard by 2007, unless additional controls to those included in the AS-4 control measure package are implemented. The modeling and attainment test results suggest a range in future-year estimated design values from 86 to 91 ppb. The higher value corresponds to the use of the 2000-2002 design value in the calculations, and the lower value corresponds to the use of the 2001-2003 DV. Use of a meteorologically adjusted DV is gives an EDV or 87 ppb. Although the EDV values are relatively high, the values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for 2007.

Oxidant tagging results indicate that 8-hour ozone concentrations in the Knoxville area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, other areas in northern Georgia, North Carolina, and South Carolina) will help to lower ozone in the Knoxville region.

Summary Attainment Demonstration for Chattanooga

The attainment and screening tests and additional corroborative analyses indicate that the Chattanooga EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

Oxidant tagging results indicate that 8-hour ozone concentrations in the Chattanooga area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia, North Carolina, and South Carolina) will contribute positively to lower ozone in the Chattanooga region.

All three of the monitoring sites in the Chattanooga area have future-year estimated design values for 8-hour ozone that are less than or equal to 85 ppb if the 2000-2002 design value is used and less than or equal to 81 ppb if the 2001-2003 design value is used. Analysis of the effects of meteorology on the design value provides an estimate of a meteorologically adjusted design value for both 2000-2002 and 2001-2003 that is equal to 86 ppb. Use of a meteorologically adjusted DV of 86 ppb is consistent with the outcome of the attainment test based on the use of the 2001-2003 DV and gives an EDV of 79 ppb. Meteorologically adjusted trends indicate a value of 83 ppb, assuming that the emissions changes between 2003 and 2007 will be, on average, the same as that for 1996-2003.

Summary Attainment Demonstration for the Tri-Cities Area

The attainment and screening tests and additional corroborative analyses indicate that the Tri-Cities EAC area will be in attainment of the 8-hour ozone standard by 2007. Both of the monitoring sites in the Tri-Cities area have future-year estimated design values for 8-hour ozone that are less than or equal to 84 ppb. The areawide 2007 EDV is 84 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 82 ppb if a meteorologically adjusted design value is used.

Maintenance Demonstration

One of the requirements of the EAC is to evaluation maintenance of the 8-hour NAAQS for 2012, five years beyond the attainment date of 2007. As part of this modeling study, a 2012 baseline emission inventory was prepared and 2012 baseline simulations were conducted. The results for 2012 show substantial additional reductions in all of the ozone metrics considered, compared to 2007. The modeling results indicate that, despite the expected growth in population between 2007 and 2012, the expected emission reductions (reflecting local EAC and national measures) provide for further improvement in ozone air quality and maintenance of the 8-hour standard in all of these areas.

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1. Introduction

This document summarizes the results of an Early Action Compact (EAC) 8-hour ozone attainment demonstration modeling analysis conducted for the States of Arkansas, Tennessee, and Mississippi. The EAC modeling exercise leveraged off the accomplishments of the ongoing Arkansas-Tennessee-Mississippi Ozone Study (ATMOS) modeling analysis, which began in April 1999 and was originally designed to provide technical information relevant to attainment of an 8-hour National Ambient Air Quality Standard (NAAQS) for ozone primarily in the Memphis, Nashville, and Knoxville areas. In addition, the ATMOS analysis was also to provide information for addressing emerging 8-hour ozone issues in the Hamilton County (Chattanooga), Tennessee; Lee County (Tupelo), Mississippi; and Little Rock, Arkansas areas. This report summarizes the methods, approaches, and results of base-case and future-year modeling conducted to support the evaluation of emission-reduction measures that have been identified by each of the states as being effective in demonstrating attainment of the 8-hour standard in 2007.

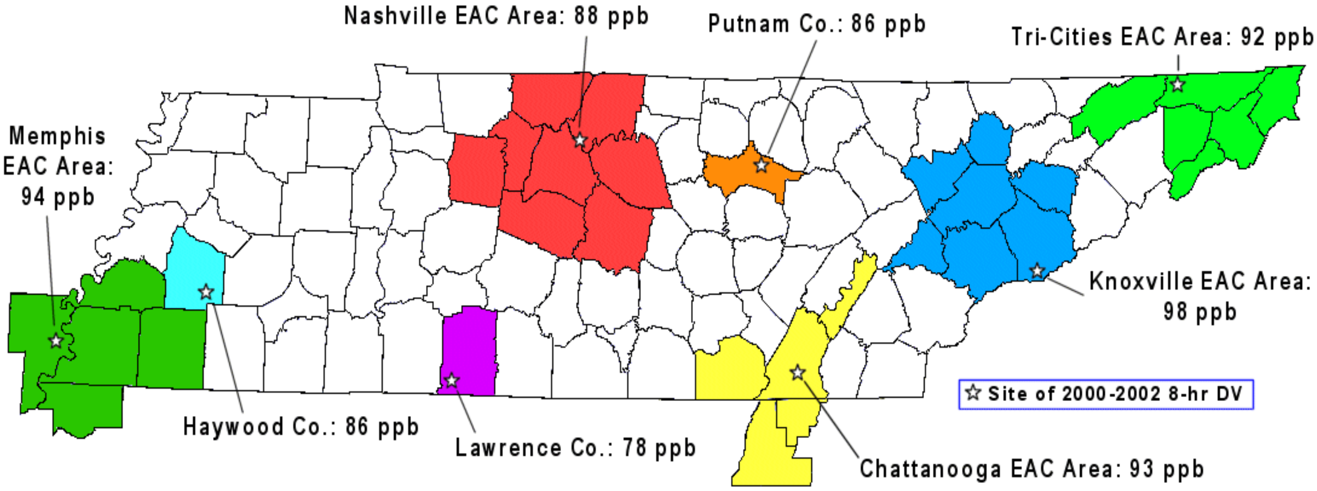
Background and Objectives

On December 31, 2002, the State of Tennessee entered into Early Action Compact agreements with EPA for eight areas within the state. The EAC areas include 30 counties within Tennessee, 2 adjacent counties in Georgia, and 1 adjacent county each in Arkansas and Mississippi, as well as 7 municipalities. The States of Arkansas and Mississippi also entered into an EAC agreement for the two counties adjacent to the Memphis area. Representatives from each of these jurisdictions signed the EAC. The EAC areas originally included the following counties:

- **Nashville EAC Area:** Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties.
- **Knoxville EAC Area:** Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties.
- **Chattanooga EAC Area:** Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa Counties, (Georgia).
- **Memphis EAC Area:** Shelby, Tipton, and Fayette Counties (Tennessee); Crittenden County (Arkansas); De Soto County (Mississippi).
- **Tri-Cities EAC Area:** Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington Counties.
- **Haywood County.**
- **Lawrence County (Florence, AL MSA).**
- **Putnam County.**

A map of the EAC areas, including the 2000-2002 design values for each area, is provided in Figure 1-1. The 8-hour ozone design value for a given monitoring site is defined as the three-year average of the fourth highest 8-hour ozone concentration at that site. The design value for a given area is the maximum of the site-specific design values over all sites in the area. The 8-hour National Ambient Air Quality Standard (NAAQS) for ozone requires the design value for an area to be less than or equal to 84 parts per billion (ppb).

Figure 1-1.
Tennessee EAC Areas with 2000–2002 Maximum 8-Hour Design Values



The ATMOS EAC modeling analysis was designed to provide technical information related to 8-hour ozone issues in the EAC areas. The EAC process provided an opportunity for these areas to conduct photochemical modeling to support decisions regarding control measures that could be adopted earlier than would be required by EPA, once the areas are formally designated nonattainment in 2004 under the new 8-hour NAAQS for ozone. Based on data for 1996-2003, the calculated design values for the areas listed above are given in Table 1-1. Based on the most recent design values as well as other considerations, Haywood, Lawrence, Johnson, and Putnam Counties opted out of the EAC process.

Table 1-1.
Maximum 8-Hour Ozone "Design Values"
for the ATMOS EAC Areas for the Period 1996-2003.

	Maximum 8-hour Ozone Design Values (ppb)					
	1996–1998	1997–1999	1998–2000	1999–2001	2000–2002	2001–2003
Memphis EAC Area	93	95	97	93	94	92
Nashville EAC Area	101	102	100	93	88	86
Knoxville EAC Area	100	104	104	98	98	92
Chattanooga EAC Area	93	94	97	92	93	87
Tri-Cities EAC Area	90	91	94	90	92	86
Haywood County	85	98	93	89	86	81
Lawrence County	84	88	89	83	78	77
Putnam County	87	88	91	87	86	82

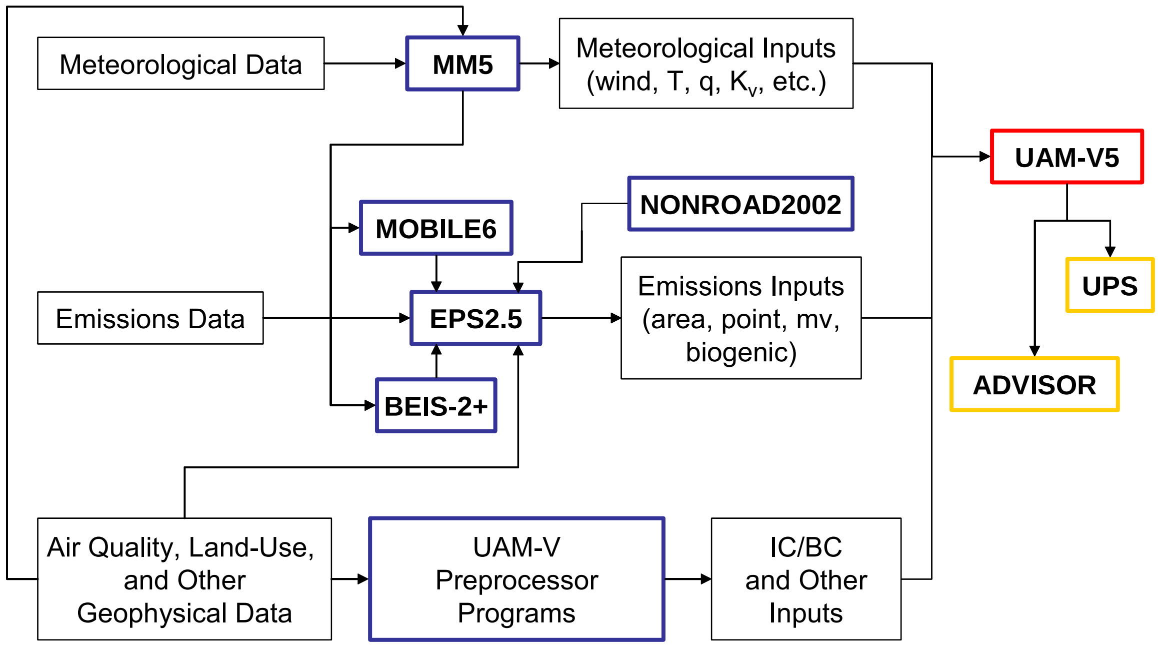
The primary objective of this study was to provide the modeling/analysis results needed to support an attainment demonstration for each of the remaining EAC areas. As such, the study was designed in accordance with draft EPA guidance (EPA, 1999a) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes. Note that while the guidance is currently in draft form, the final version is not expected to be substantively different from the draft.

The ATMOS EAC modeling analysis components included a comprehensive episode selection analysis (identifying suitable periods for modeling), application and evaluation of a photochemical modeling system for three simulation periods, projection of emissions and ozone concentrations for two future years, and evaluation of ozone attainment strategies. The existing ATMOS committee structure (Technical, Operations, and Policy) was used throughout this study to support the technical work and as a means of communicating with all participants. All technical tasks were conducted in accordance with the draft EPA guidance and interim results of the analysis were presented in multiple meetings of the ATMOS Technical Committee and disseminated through the ATMOS web site (http://www.atmos.saintl.com).

Overview of the Modeling System Used for This Study

The ATMOS EAC modeling analysis utilized much of what was established for the original ATMOS analysis in terms of modeling tools and modeling domain specifications. The primary modeling tools selected for use in this study include: the variable-grid Urban Airshed Model (UAM-V) Version 1.5, a regional- and urban-scale, nested-grid photochemical model; the Emission Preprocessor System (EPS2.5), for preparation of model-ready emission inventories; the Biogenic Emission Inventory System with high-resolution land-use and crop data (BEIS-2+), for estimating biogenic emissions; the MOBILE6 model, for estimating motor-vehicle emissions; EPA's NONROAD2002a model, which calculates non-road emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The UAM-V modeling system outputs were summarized and displayed using the UAM-V Postprocessing System (UPS) and the ATMOS ACCESS Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR). Figure 1-2 provides an overview of the ATMOS EAC modeling system, including key input data requirements, UAM-V input files, and interactions among the modeling system components.

Figure 1-2.
Schematic Diagram of the ATMOS EAC Photochemical Modeling System



Overview of the UAM-V Modeling System

The variable-grid Urban Airshed Model (UAM-V) is a three-dimensional photochemical grid model that calculates concentrations of pollutants by simulating the physical and chemical processes in the atmosphere. The basis for the UAM-V is the atmospheric diffusion or species continuity equation. This equation represents a mass balance that includes all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes in mathematical terms.

The major factors that affect photochemical air quality include:

- The pattern of emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOC), both natural and anthropogenic.
- Composition of the emitted VOC and NO_x.
- Spatial and temporal variations in the wind fields.
- Dynamics of the boundary layer, including stability and the level of mixing.
- Chemical reactions involving VOC, NO_x, and other important species.
- Diurnal variations of solar insolation and temperature.
- Loss of ozone and ozone precursors by dry and wet deposition.
- Ambient background of VOC, NO_x, and other species in, immediately upwind of, and above the study region.

The UAM-V simulates all of these processes. The species continuity equation is solved using the following fractional steps: emissions are injected; horizontal advection/diffusion are solved; vertical advection/diffusion and deposition are solved; and chemical transformations are performed for reactive pollutants. The UAM-V performs these four calculations during each time step. The maximum time step is a function of the grid size, maximum wind velocity, and diffusion coefficient. The typical time step is 10–15 minutes for coarse (10–20 km) grids and a few minutes for fine (1–2 km) grids.

Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is ideal for evaluating the air-quality effects of emission control scenarios. This is achieved by first replicating a historical ozone episode to establish a base-case simulation. Model inputs are prepared from observed meteorological, emissions, and air quality data for the episode days using dynamic meteorological modeling and/or diagnostic and interpolative techniques. The model is then applied with these inputs, and the results are evaluated to assess model performance. Once the model results have been evaluated and determined to perform within prescribed levels, the same base-case meteorological inputs are combined with *modified* or *projected* emission inventories to simulate possible alternative/future emission scenarios.

The UAM-V modeling system (Version 1.5) incorporates the latest version of the Carbon-Bond chemical mechanism, known as Carbon Bond 5 (CB-V), with enhanced isoprene chemistry (SAI, 2002). Features of the UAM-V modeling system include:

- **Variable vertical grid structure:** The structure of vertical layers can be arbitrarily defined. This allows for higher resolution near the surface and facilitates matching with output from prognostic meteorological models.
- **Three-dimensional meteorological inputs:** The meteorological inputs for UAM-V vary spatially and temporally. These are usually calculated using a prognostic meteorological model.
- **Variable grid resolution for chemical kinetic calculations:** A chemical aggregation scheme can be employed, allowing chemistry calculations to be performed on a variable grid while advection/diffusion and emissions injections are performed on a fixed grid.
- **Two-way nested grid:** Finer grids can be imbedded in coarser grids for more detailed representation of advection/diffusion, chemistry, and emissions. Several levels of nesting can be accommodated.
- **Updated chemical mechanism:** The original Carbon Bond IV chemical mechanism has been updated to include many additional reactions. The updated chemical mechanism (CB-V) also supports the enhanced treatment of isoprene and hydrocarbon species.
- **Dry deposition algorithm:** The dry deposition algorithm is similar to that used by the Regional Acid Deposition Model (RADM).
- **True mass balance:** Concentrations are advected and diffused in the model using units of mass per unit volume rather than parts per million. This maintains true mass balance in the advection and diffusion calculations.
- **Plume-in-grid treatment:** Emissions from point sources can be treated by a subgrid-scale Lagrangian photochemical plume model. Pollutant mass is released from the subgrid-scale model to the grid model when the plume size is commensurate with grid cell size.

- **Plume rise algorithm:** The plume rise algorithm is based on the plume rise treatment for a Gaussian dispersion model.
- **OPTM method for ozone apportionment estimates:** The Ozone and Precursor Tagging Methodology (OPTM) approach allows the user to estimate contributions to ozone formation from various source categories or regions. The method tags oxidant formed during the chemistry step and attributes it to the NO_x and VOC participating in the chemistry during that step. At the end of a run the user can analyze the results based on the accumulated effects to help determine the most effective control strategies for ozone reduction.

Modeling Grid Specification

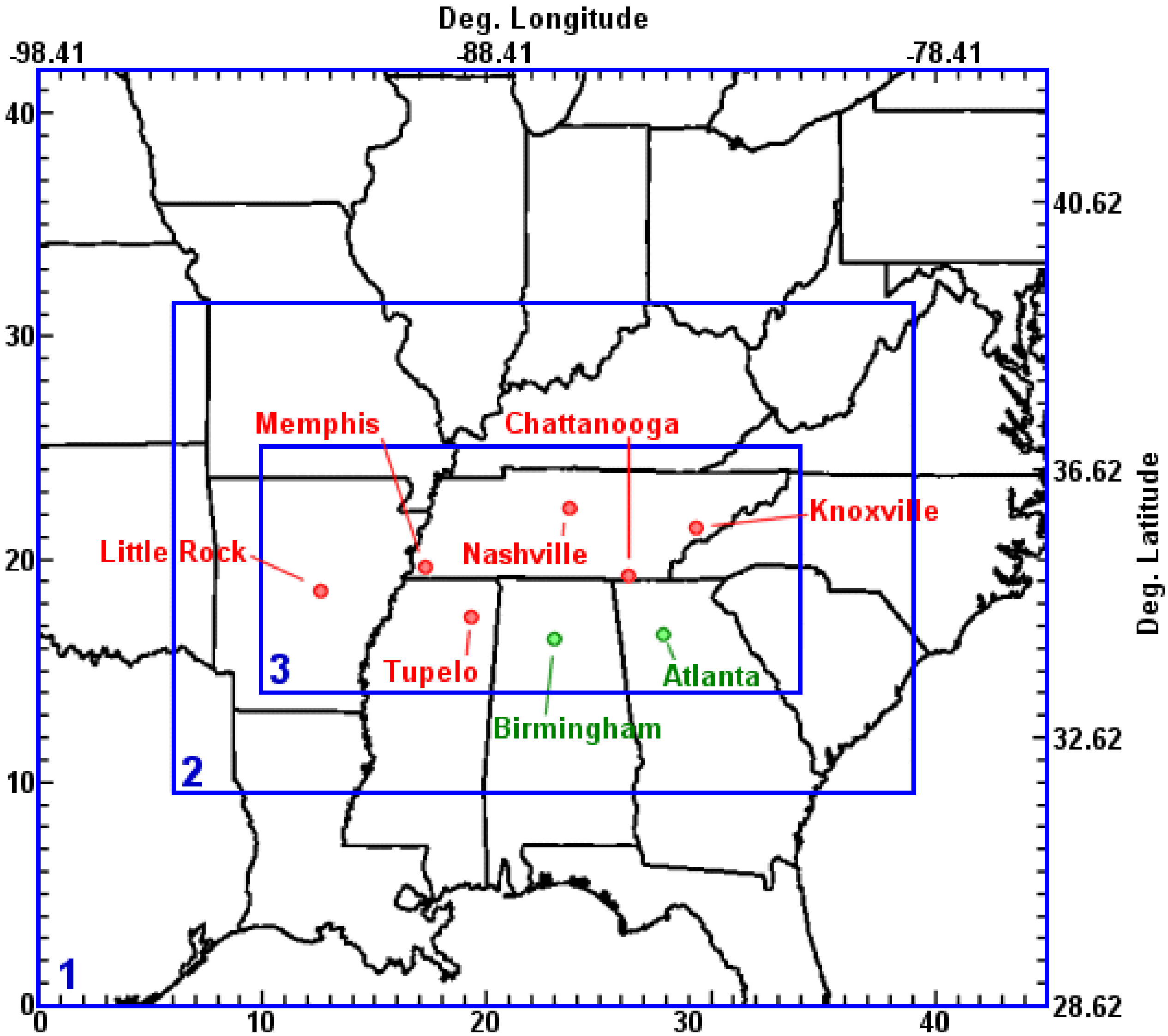
The modeling domain for application of the UAM-V for the ATMOS EAC analysis was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the area of interest. The modeling domain used in the EAC modeling analysis is the same as what has been used for the original ATMOS modeling. The UAM-V modeling domain is presented in Figure 1-3 and includes a 36-km resolution outer grid encompassing the southeastern U.S; a 12-km resolution intermediate grid; and a 4-km resolution inner grid encompassing Tennessee and portions of Mississippi, Arkansas, and other neighboring states.

The regional extent of the modeling domain is intended to provide realistic boundary conditions for the primary areas of interest and thus avoid some of the uncertainty introduced in the modeling results through the incomplete and sometimes arbitrary specification of boundary conditions. The use of 4-km grid resolution over the primary area of interest is consistent with an urban-scale analysis of each of the areas of interest.

The UAM-V domain is further defined by eleven vertical layers with layer interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters (m) above ground level (agl).

The modeling domain for application of MM5 is shown in Figure 1-4. This domain is much larger than that for UAM-V, in order to enable the simulation of any important synoptic scale features and their influence on the regional meteorology. The modeling domain consists of an extended outer grid with approximately 108-km horizontal resolution and three inner (nested) grids with approximately 36, 12, and 4-km resolution. The horizontal resolution was specified to match that for UAM-V. A one-way nesting procedure and 22 vertical levels were employed. The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights for application of MM5 are listed in Table 1-2.

Figure 1-3.
UAM-V Modeling Domain for the ATMOS Study



Grid 1: (-98.41,28.62)—45x42—36-km Cells
Grid 2: (-95.41,31.79)—99X66—12-Km Cells
Grid 3: (-93.41,33.96)—215x81—4-km Cells

Figure 1-4.
MM5 Modeling Domain for the ATMOS Application

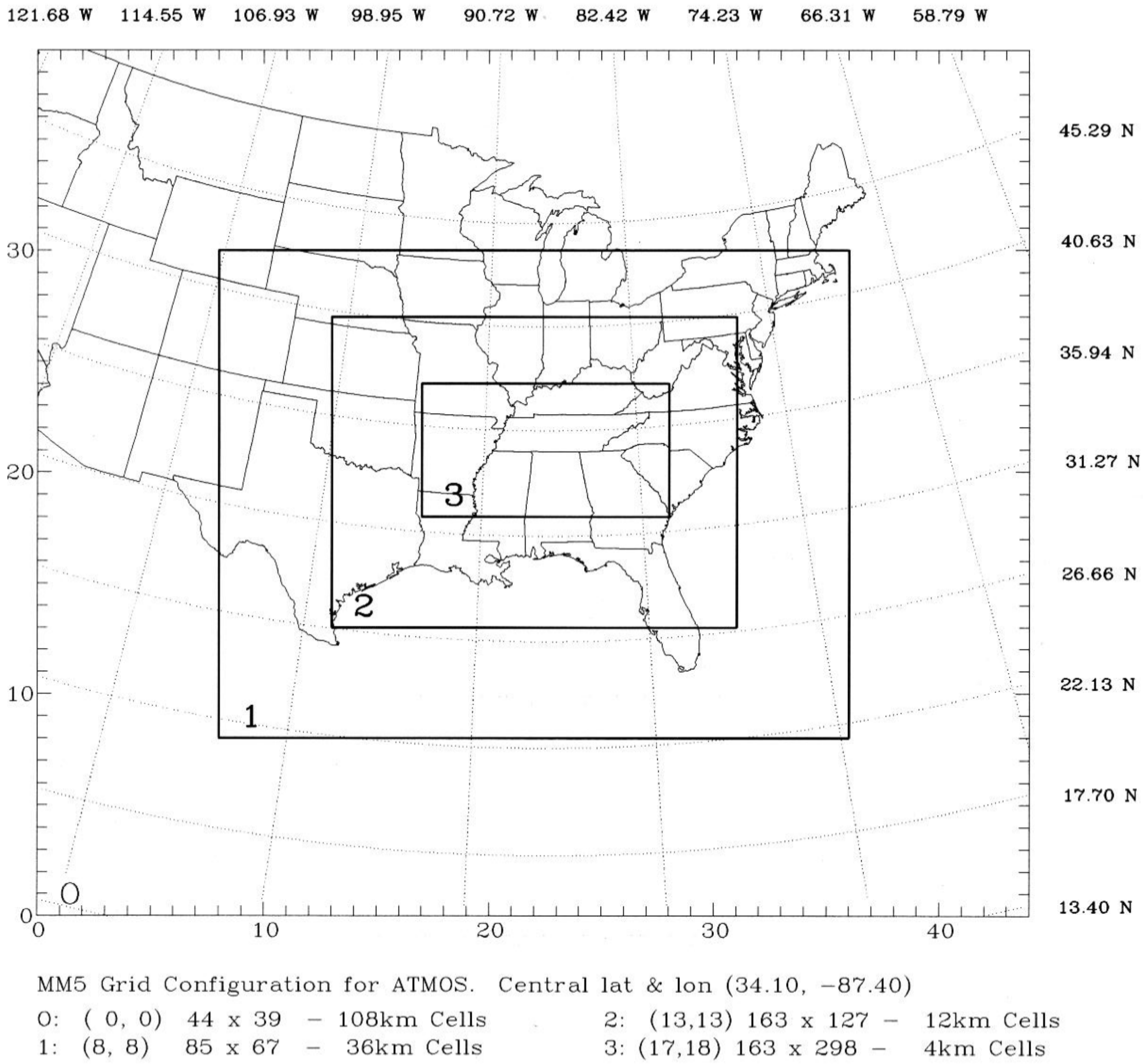


Table 1-2.
MM5 Vertical Levels for the ATMOS Application

Level	Sigma	Average Height (m)
1	0.996	30
2	0.988	80
3	0.982	125
4	0.972	215
5	0.960	305
6	0.944	430
7	0.928	560
8	0.910	700
9	0.890	865
10	0.860	1115
11	0.830	1370
12	0.790	1720
13	0.745	2130
14	0.690	2660
15	0.620	3375
16	0.540	4260
17	0.460	5240
18	0.380	6225
19	0.300	7585
20	0.220	9035
21	0.140	10790
22	0.050	13355

Conceptual Description for 8-Hour Ozone for the ATMOS EAC Areas

Developing a conceptual model for 8-hour ozone is an important component of any 8-hour ozone modeling analysis. The conceptual model sets the stage for understanding the physical and chemical factors that influence ozone concentrations within the area of interest and that potentially result in exceedances of the 8-hour ozone standard, and for subsequently determining the extent to which secondary (upwind or downwind) areas need to be encompassed within the modeling domain and included in the assessment of the results with respect to ozone and precursor transport. The conceptual model also provides the basis for identifying the type and frequency of occurrence of different types of 8-hour ozone episodes and thus for the selection of modeling episode periods or key days for analysis of the modeling results. Finally, the conceptual model serves to provide focus to the interpretation of the modeling results and the development of effective attainment strategies.

In this section of the technical support document, we rely on observed air quality and emissions data to describe and characterize 8-hour ozone issues in the ATMOS EAC areas. We begin with a brief overview of the basics of ozone formation.

Overview of Ozone Chemistry

Ozone is a secondary pollutant that is not directly emitted into the atmosphere but instead is formed in the lower atmosphere by a series of reactions involving ultra violet (UV) radiation and precursor emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOC). NO_x consists of nitric oxide (NO) and nitrogen dioxide (NO_2), which are primarily emitted from anthropogenic sources. VOC consist of thousands of individual hydrocarbon and oxygenated hydrocarbon species emitted from both man-made and biogenic sources. Ozone formation near the earth's surface is affected by local weather conditions: winds, temperature, solar radiation, and horizontal and vertical dispersion characteristics, which influence precursor concentrations, reaction rates, formation, transport, and deposition.

On a typical summer day in the troposphere, UV radiation breaks the NO_2 molecule into NO and O (the oxygen atom). The oxygen atom then reacts with atmospheric oxygen (O_2) to form ozone (O_3). In another reaction, NO also reacts with ozone, destroying it and regenerating NO_2 and O_2. The role of VOC is a bit more complicated. Reactions involving VOC permit ozone to accumulate to higher concentrations by regenerating NO_2 from NO through free-radical reactions that do not destroy ozone, thus suppressing the destruction of ozone by NO. In the absence of VOC, ozone reaches a low steady-state concentration. Because the primary ozone-forming reaction is photochemically driven (i.e., by the sun), ozone concentrations typically peak during the daylight hours and then decrease after sunset.

In photochemical modeling, we are most interested in how changes in the emissions of NO_x and VOC affect the resultant ozone concentrations. In this case, it is NO_x that is more complicated. The chemical reactions tell us that reducing VOC emissions will always lead to slower rates of ozone formation and lower ambient ozone concentrations. Since NO_x emissions are needed to initiate ozone formation, reducing NO_x emissions will also tend to slow the rate of ozone formation. In some circumstances, however, reducing NO_x emissions will accelerate ozone formation (increase ozone concentrations) by limiting the rate of ozone destruction. When NO_x

emissions are reduced such that the VOC to NO_x ratio exceeds about 5.5:1, free radicals react primarily with VOC, breaking them down in a combustion-like process that accelerates ozone formation. This is most likely to occur during the nighttime hours and in areas where the ratio of VOC to NO_x concentrations is relatively low.

Regional-Scale Ozone Concentrations and Patterns

To aid our understanding of the regional-scale ozone concentration patterns for the ATMOS EAC areas and surrounding areas, we examined 8-hour ozone concentrations throughout the region, and specifically for the key areas of interest and other major metropolitan areas within the high-resolution ATMOS modeling subdomain (Grid 3). Please note that the Great Smoky Mountains National Park is a part of the Knoxville EAC area and is considered as such in this analysis. In keeping with the episode selection analysis, we specifically examined the period 1996-2002. This seven-year period was selected to optimize data availability for a consistent set of monitoring sites, to capture the range of meteorological conditions associated with ozone exceedances in the areas, and to limit the influence of emissions changes on the analysis and interpretation of results.

Table 1-3 presents some basic metrics calculated from the daily maximum 8-hour ozone value over all sites for each area. Eight-hour NAAQS exceedance days are fairly common for all sites, comprising at least 10 percent of the days for Memphis, Nashville, Knoxville, and Atlanta, with the worst 8-hour ozone—in terms of frequency and severity—at Knoxville and Atlanta. Chattanooga and the Tri-Cities area have lower 8-hour ozone but still see a significant number of exceedance days.

Table 1-3.
8-Hour Ozone Metrics for Areas of Interest, from 1996 to 2002, April to October Inclusive[1]

Average annual maximum values and percentiles are in ppb.

1996-2002	Memphis	Nashville	Knoxville	Chattanooga	Tri-Cities	Atlanta	Birmingham
Data availability	100%	100%	100%	98%	98%	86%	85%
Avg. annual max.	112.99	109.87	113.94	106.36	101.54	128.04	114.27
Exceedance days	150	162	278	94	65	281	113
90th percentile	85.0	85.9	92.3	80.3	78.4	98.8	83.3
50th percentile	60.1	61.5	69.9	56.6	55.9	65.5	56.6
10th percentile	37.1	38.5	52.0	33.0	35.6	40.5	35.1

Figure 1-5 shows the frequency of exceedances for each month, averaged over available years. For all areas, the peak ozone season occurs in the mid summer, with a peak in the number of exceedance days around August.

Individual years can be compared in Figure 1-6, which shows the changing value for the 90th percentile of each year's daily maximum 8-hour ozone values. Here again the pattern is fairly

[1] Although March is now considered an ozone-season month, it was not included in our analysis.

consistent for all sites, with high ozone occurring in 1998 and 1999, and relatively low levels in 2001.

Figure 1-5.
Number of 8-Hour Exceedance Days per Month, Averaged over Years 1996 to 2002

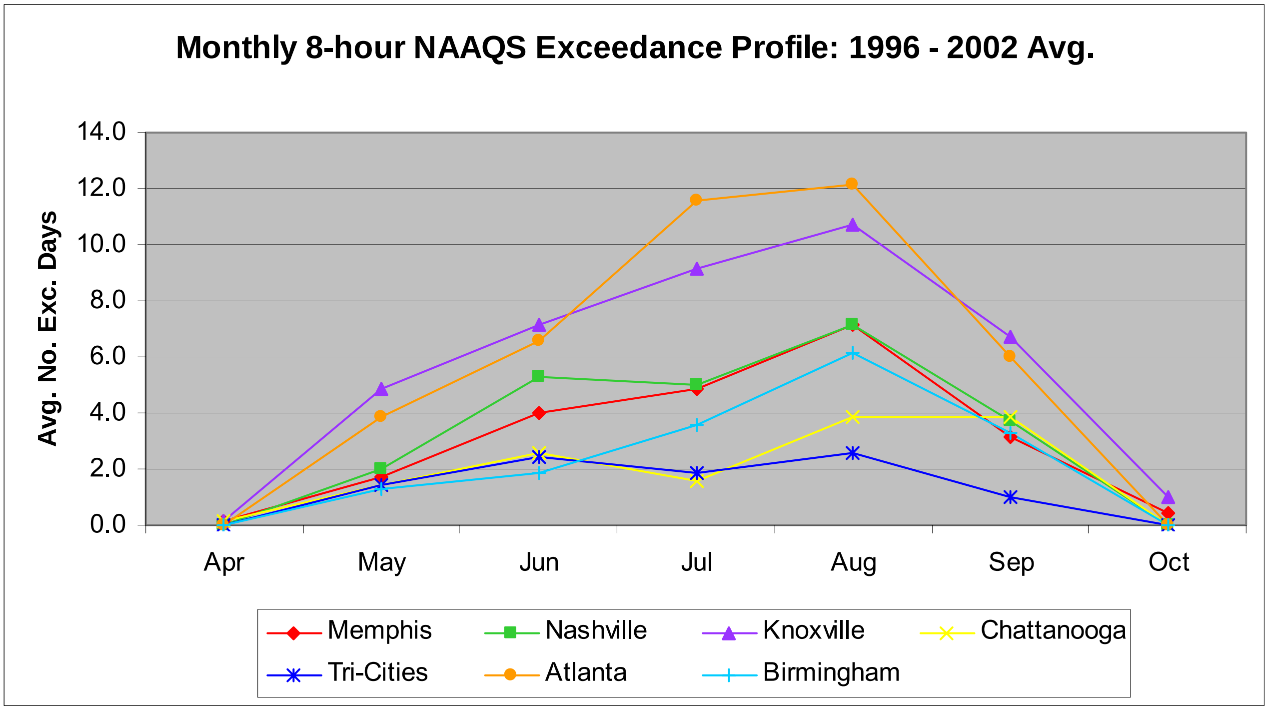
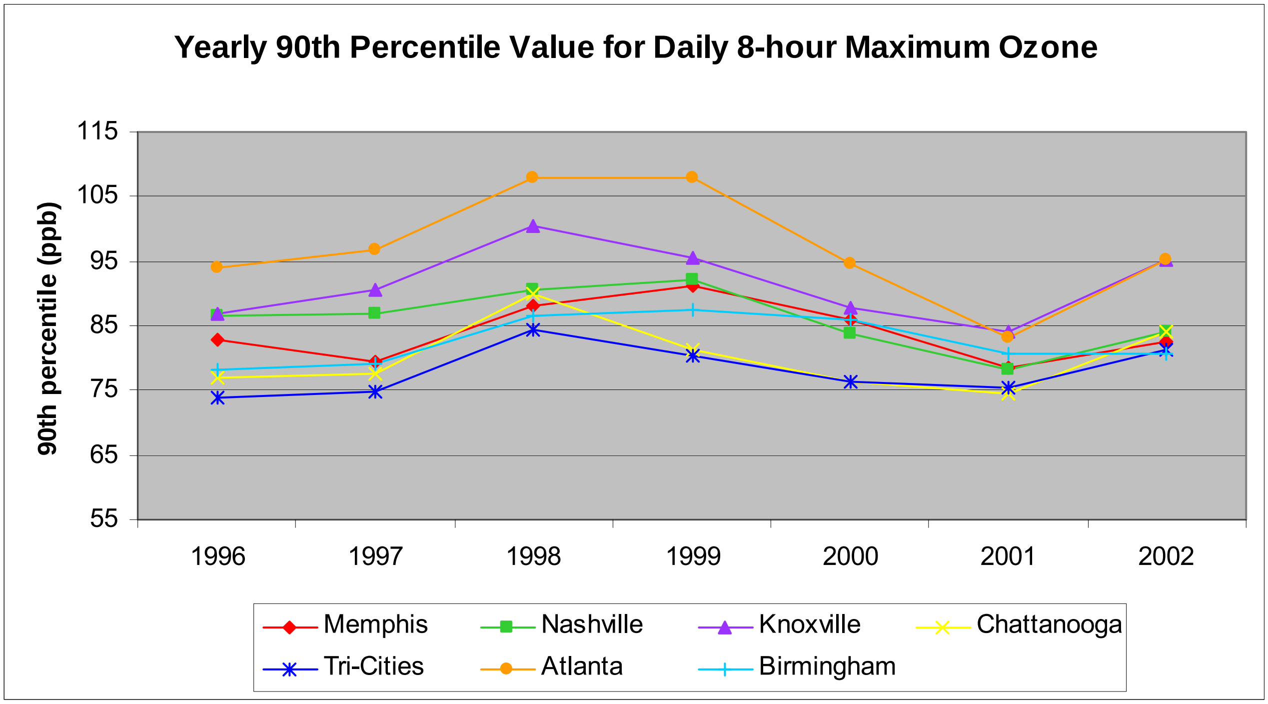


Figure 1-6.
Each Year's Ninetieth Percentile Value for Daily Maximum 8-Hour Ozone Values



To examine the regional-scale nature of high ozone, we also looked for correlations between the observed values for each area listed in Table 1-3 above. For this analysis, the correlation (R) is defined as the sample covariance between two datasets divided by the product of the standard deviations for each dataset, which is equivalent to:

$$R = \left(n\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)\right) \Big/ \sqrt{\left(n\sum X^2 - \left(\sum X\right)^2\right)\left(n\sum Y^2 - \left(\sum Y\right)^2\right)}$$

where the two datasets X and Y each have n data points.

R-squared is simply the square of the correlation; a value over 0.70 may be considered significant. Table 1-4 shows R-squared values for same-day 8-hour maximum ozone values, for every area combination, using all days with data for each area in the pair. It is apparent from the table that the R-squared values reflect and quantify the neighbor-to-neighbor correlations one might expect. For these correlations, between 1250 and 1500 data points are available for each pairing.

Table 1-4.
R-Squared Values for 8-Hour Ozone Daily Maximums for Areas of Interest, 1996-2002.

Shaded values are between different sites with their squared correlation greater than 0.50.

R-squared value	Memphis	Nashville	Knoxville	Chattanooga	Tri-Cities	Atlanta	Birmingham
Memphis	1.00	0.63	0.39	0.43	0.25	0.30	0.42
Nashville		1.00	0.64	0.66	0.47	0.47	0.49
Knoxville			1.00	0.68	0.67	0.59	0.44
Chattanooga				1.00	0.61	0.59	0.53
Tri-Cities					1.00	0.40	0.27
Atlanta						1.00	0.64
Birmingham							1.00

Moderate correlation appears between nearby areas, perhaps reflecting similar meteorological conditions. We also examined correlations with a one-day lag between the areas; only one of these gave R-squared values greater than 0.50: Knoxville and yesterday's Nashville have an R-squared value of 0.54. For Chattanooga, the correlation between the area 8-hour maximum and Chattanooga's own previous-day value was similar to the correlation between that area and previous-day Memphis or Nashville (all R-squared values between 0.42 and 0.44); the same is true for Tri-Cities related to its own previous-day value, Nashville, and Knoxville (R-squared values between 0.40 to 0.42). Nashville 8-hour ozone is correlated to its own previous-day ozone slightly more than to the previous-day ozone in Memphis (R-squared values of 0.48 and 0.45, respectively). For Memphis, the correlation to its own previous-day value is significantly greater than to any other site's previous day value. However, none of these correlations are very dramatic, the highest being between Knoxville and its own previous-day value, with R-squared of 0.57.

These results suggest that same-day 8-hour ozone concentrations are somewhat subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions. Within the context of the correlations, there is also the possibility that ozone from one area affects ozone concentrations in one or more neighboring areas, in particular, transport from west Tennessee to Chattanooga and the Tri-Cities area, or between Atlanta and Birmingham and Tennessee.

ATMOS EAC Area Ozone Concentrations and Patterns

We also examine the 8-hour ozone characteristics of the individual AIRS sites of each EAC area. This provides some insight into the site-specific concentration characteristics and allows us to highlight the key high ozone sites as well as the extent of high ozone across each area.

Site-Specific 8-Hour Ozone Concentration Characteristics

Table 1-5a through 1-5e give the same overview as Table 1-3, except here the daily 8-hour ozone maximums are for individual sites instead of for areas.

Table 1-5a.
8-Hour Ozone Metrics for Sites in the Memphis EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Edmond Orgill Park	Frayser Blvd.	Marion, AR	DeSoto County, MS
Data availability	99%	99%	97%	95%
Avg. annual max.	100.2	108.3	101.2	102.7
Exceedance days	80	53	55	43
90th percentile	78.9	75.4	76.4	74.4
50th percentile	57.8	51.9	54.6	53.6
10th percentile	36.1	30.5	33.8	32.6

Table 1-5b.
8-Hour Ozone Metrics for Sites in the Nashville EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	E. Nashville Health Center	Percy Priest Dam	Rutherford Co.	Rockland Rd.	Cottontown Wright's Farm	Fairview	Cedars of Lebanon State Park
Data availability	99%	98%	94%	96%	96%	96%	96%
Avg. annual max.	90.6	98.7	95.1	106.3	98.27	98.46	100.14
Exceedance days	23	40	37	106	39	65	44
90th percentile	67.4	72.9	74.1	81.0	72.8	77.9	76.6
50th percentile	44.4	51.4	53.9	56.5	52.8	57.4	54.5
10th percentile	24.1	29.4	34.7	33.4	32.1	36.9	33.0

Table 1-5c.
8-Hour Ozone Metrics for Sites in the Knoxville EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	East Knoxville	Spring Hill	Jefferson Co.	Anderson Co.	Cove Mountain	Clingman's Dome	Cades Cove	Look Rock
Data availability	99%	100%	95%	94%	94%	81%	94%	80%
Avg. annual max.	110.39	110.13	107.7	96.7	103.21	104.24	89.6	88.6
Exceedance days	120	124	122	65	158	135	16	108
90th percentile	82.5	83.4	83.1	79.1	86.3	86.3	72.2	83.7
50th percentile	58.1	56.9	58.6	56.3	65.8	67.6	53.1	62.0
10th percentile	35.1	32.4	37.3	34.4	48.4	51.8	34.1	43.6

Table 1-5d.
8-Hour Ozone Metrics for Sites in the Chattanooga EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Chattanooga - VAAP	Sequoyah
Data availability	90%	97%
Avg. annual max.	103.4	105.3
Exceedance days	70	72
90th percentile	79.0	77.5
50th percentile	55.8	53.9
10th percentile	31.6	31.9

Table 1-5e.
8-Hour Ozone Metrics for Sites in the Tri-Cities EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Kingsport	Blountville
Data availability	97%	96%
Avg. annual max.	100.3	97.9
Exceedance days	63	43
90th percentile	77.4	75.5
50th percentile	54.9	54.1
10th percentile	34.3	32.6

The indicators of high ozone don't favor one site in the Memphis area during the entire period. The Edmund Orgill Park site has the most number of exceedances during the analysis period, while the Frayser site has the highest average of the annual maximum values. In recent years, however, the Marion site has experienced a greater number of exceedance days than either site in Shelby Co. and the higher values have also shifted to this site. Consequently, the Marion site currently has the highest design value for the Memphis area.

For the most part, a single site (Rockland Rd.) drives 8-hour ozone exceedances in the Nashville area. Several Knoxville sites see 10 percent of days at exceedance or near-exceedance 8-hour ozone levels: East Knoxville, Spring Hill, Jefferson County, Cove Mountain, Clingman's Dome, and Look Rock. For Chattanooga, both sites experience high ozone about equally; in the Tri-Cities area the Kingsport site tends to slightly higher 8-hour ozone and more exceedances than Blountville.

Diurnal Patterns

The diurnal ozone concentration patterns vary among the sites within each region, depending upon the site location relative to the emissions sources and various meteorological influences. Composite diurnal profiles for selected key sites for each area for exceedance days only are presented in Figures 1-7a through 1-7e.

Because the Memphis area incorporates portions of three states, we show the average diurnal profiles for three sites—one from each state—in Figure 1-7a. The Frayser site located in Shelby Co., TN is characterized by a classic or typical diurnal profile with the peak ozone concentration in the early to mid afternoon. Concentrations during the nighttime hours are low, as ozone is titrated by NO emissions with the area. Ozone concentrations at the Marion and DeSoto County sites tend to peak later in the day, late afternoon to early evening. This indicates that ozone formed elsewhere in the domain (during the time of peak solar insolation) is transported to these sites and contributes to the maximum 1-hour and 8-hour ozone concentrations.

For the Nashville area (Figure 1-7b), the Rockland Road monitor consistently reports the highest values. It is characterized by a typical diurnal profile with a peak value during the middle of the day. This suggests that most of the ozone observed at this site is formed locally.

The Knoxville EAC area incorporates two distinct regions – the greater Knoxville area and the Great Smoky Mountains (GSM) National Park. In Figure 1-7c, average diurnal profiles for the Spring Hill monitor characterize the more urbanized area while those for Clingman's Dome are representative of the GSM area. The average exceedance-day diurnal profile for Spring Hill shows a mid-day peak. The elevated GSM sites (with elevations on the order of 600 to 1000 m) show very flat diurnal profiles, as illustrated by the profile for the Clingman's Dome site. The lack of variation throughout the day and specifically the lack of a distinct daytime peak indicate that ozone is transported into this area throughout the day (and not specifically formed during the daytime hours). Without local emission sources, titration of ozone during the nighttime hours also does not occur. The high 8-hour average ozone concentrations are due to the sustained relatively high ozone values rather than a combination of high and moderate values (as is the case for most urban sites).

For the Chattanooga and Tri-Cities areas (Figures 1-7d and 1-7e, respectively), the monitors are characterized by a typical diurnal profile with a peak value during the middle of the day.

Figure 1-7a.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Memphis EAC Area.

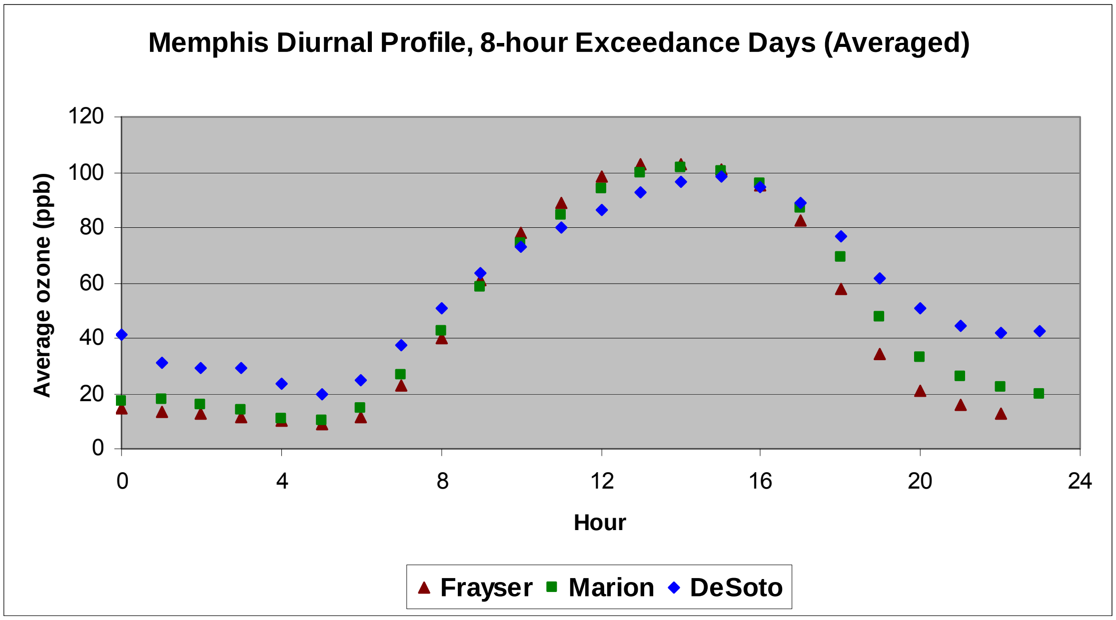


Figure 1-7b.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Nashville EAC Area.

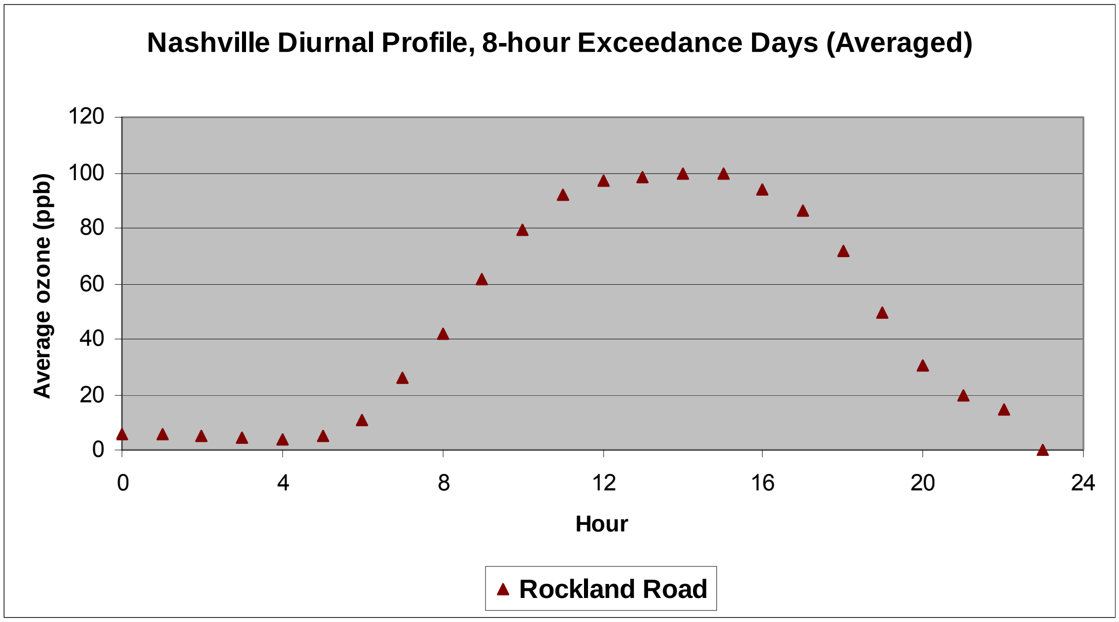


Figure 1-7c.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Knoxville EAC Area.

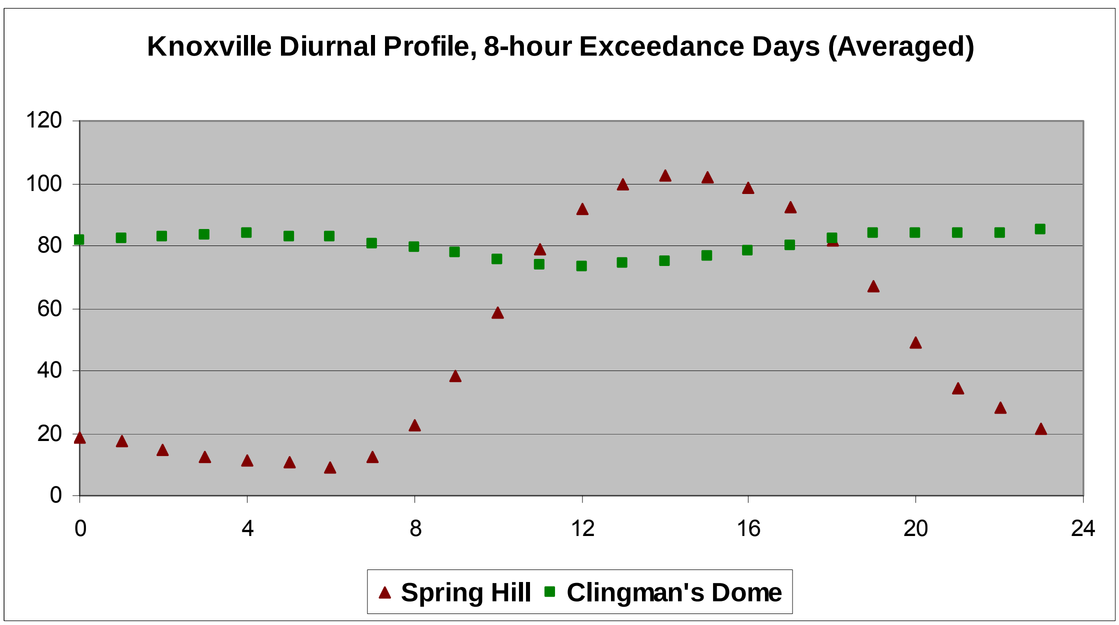


Figure 1-7d.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Chattanooga EAC Area.

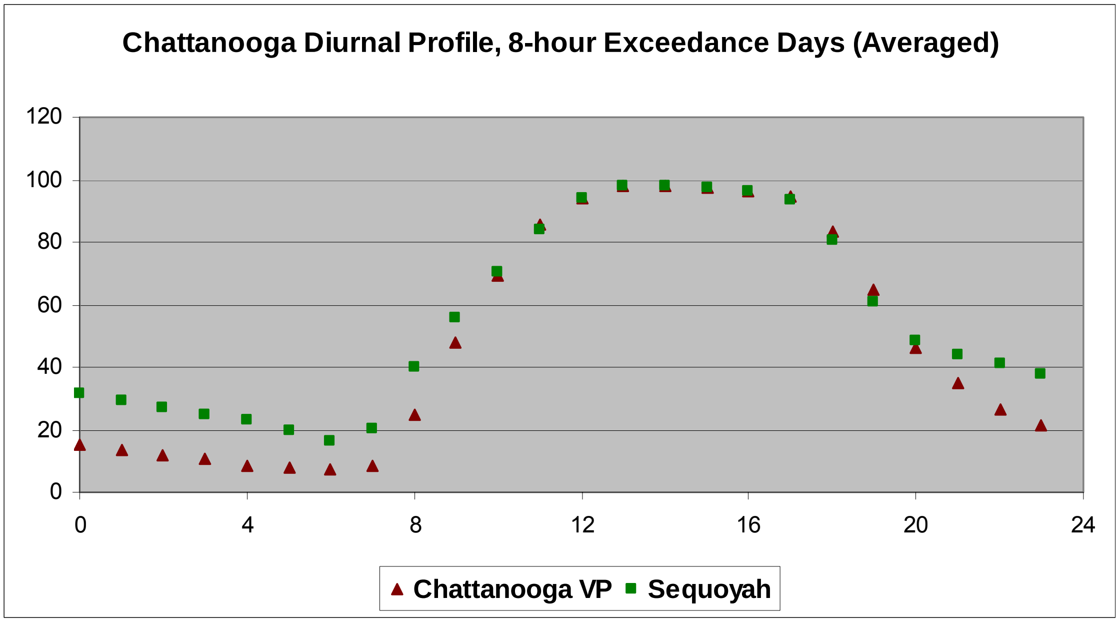
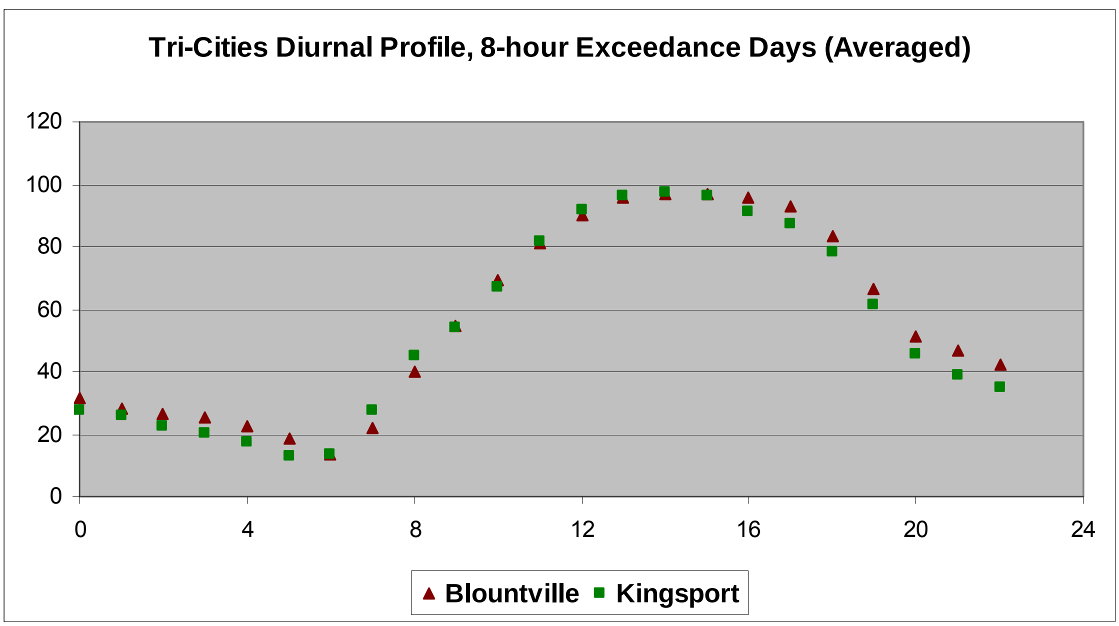


Figure 1-7e.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Tri-Cities EAC Area.



Meteorological Characteristics of Ozone Episodes

Overview of Meteorological Factors Influencing Ozone

Ozone episodes for many areas in the U.S. are often characterized relative to regional-scale meteorological high- and low-pressure patterns and specifically to the presence of a surface-based high-pressure system (an area over which the atmospheric pressure is relatively higher than the surrounding areas). The location of the high-pressure system relative to the area of interest determines the prevailing wind and dispersion conditions and thus the source-receptor relationships that characterize an ozone episode, whereas the persistence and strength of the system influence/determine episode severity. A textbook depiction of an ozone episode places the high-pressure system over an urban area. This results in suppressed vertical mixing of emissions/pollutants, low wind speeds or stagnation, low humidity, high temperatures, clear skies, and strong solar insolation. These are the typical ingredients of an ozone episode.

The “recipe” for high ozone concentrations varies throughout the U.S. according to geographical characteristics, local and regional emissions characteristics, and the location of each area relative to other areas in combination with pollutant-transport-conducive meteorological conditions. The complexity of any conceptual model for ozone formation increases with each of these factors.

Ozone episodes within each of the EAC areas occur under a variety of regional-scale meteorological conditions and prevailing wind directions. The regional-scale patterns, in turn, influence the development of local ozone-conducive meteorological conditions. We explore both of these, in turn, in the remainder of this section.

Analysis of Exceedance and Non-Exceedance Regional Wind Patterns

Plots comparing the frequency of wind directions and speeds for all ozone season days (April through October) and 8-hour ozone exceedance days in each of the EAC areas of interest for the period 1996-2002 are presented in Figures 1-8 through 1-12. The wind information in these plots is for the Nashville upper-air monitoring site. Because Nashville is centrally located within the region of interest, these data are used here to represent the regional-scale winds. In these diagrams, wind direction is defined as the direction from which the wind is blowing. The length of the bar within that wind-direction sector indicates the frequency of occurrence of a particular wind direction. The shading indicates the distribution of wind speeds.

Upper-air winds for the 850 mb level (approximately 1500 m above ground) are available twice per day, at approximately 0600 and 1800 LST. Distinguishing features in the wind plots (also called wind rose diagrams) for the ozone exceedance days, when contrasted to those for all ozone-season days, may help to define the wind and/or transport patterns leading to high ozone. The wind distributions for the ozone season are presented in Figure 1-8. Those for the 8-hour exceedance days for each area follow.

Based on the Nashville sounding data (Figure 1-8a-b), upper-level winds during the ozone season tend to be southwesterly through northwesterly for both the morning and evening soundings.

When only high ozone days in the Memphis area are considered (Figure 1-9), there is a discernable shift to more northerly and easterly components during the time of the morning sounding, and really no favored wind direction at the time of the evening sounding. The percentage of time that the winds are from the north, northeast, south, and southeast is greater for ozone exceedance days than for all ozone season days. The range of wind directions indicates that there is no one upper-air wind pattern associated with exceedances in the Memphis area. We also examined this same series of plots using upper-air wind data for Little Rock (not shown) and found a greater occurrence of easterly winds at the time of the morning sounding and a slight tendency for a shift from southwesterly to southeasterly winds at the time of the afternoon sounding for exceedance days in Memphis.

For the Nashville area (Figure 1-10), the upper-level winds suggest a greater tendency for winds aloft to have a westerly component during the time of the morning sounding, but easterly wind components also appear on certain of the exceedance days. Similar to Memphis, the evening winds exhibit a range of wind directions on ozone exceedance days for Nashville, with a tendency for more southerly and easterly wind components on the exceedance days.

For exceedance days in the Knoxville area (Figure 1-11), the upper-level winds suggest a greater tendency for winds aloft to have a southerly component during high ozone days, especially at the time of the evening soundings. Westerly to southwesterly winds dominate the wind roses for the Knoxville area ozone exceedance days.

Westerly to southerly winds also dominate the wind roses for exceedances days in the Chattanooga area (Figure 1-12). Compared to the full ozone season, there is a greater tendency for winds from south.

Figure 1-8a.
Winds at the 850 mb Level for the Nashville Sounding for the Ozone Season (April–October, 1996–2002): 0600 CST

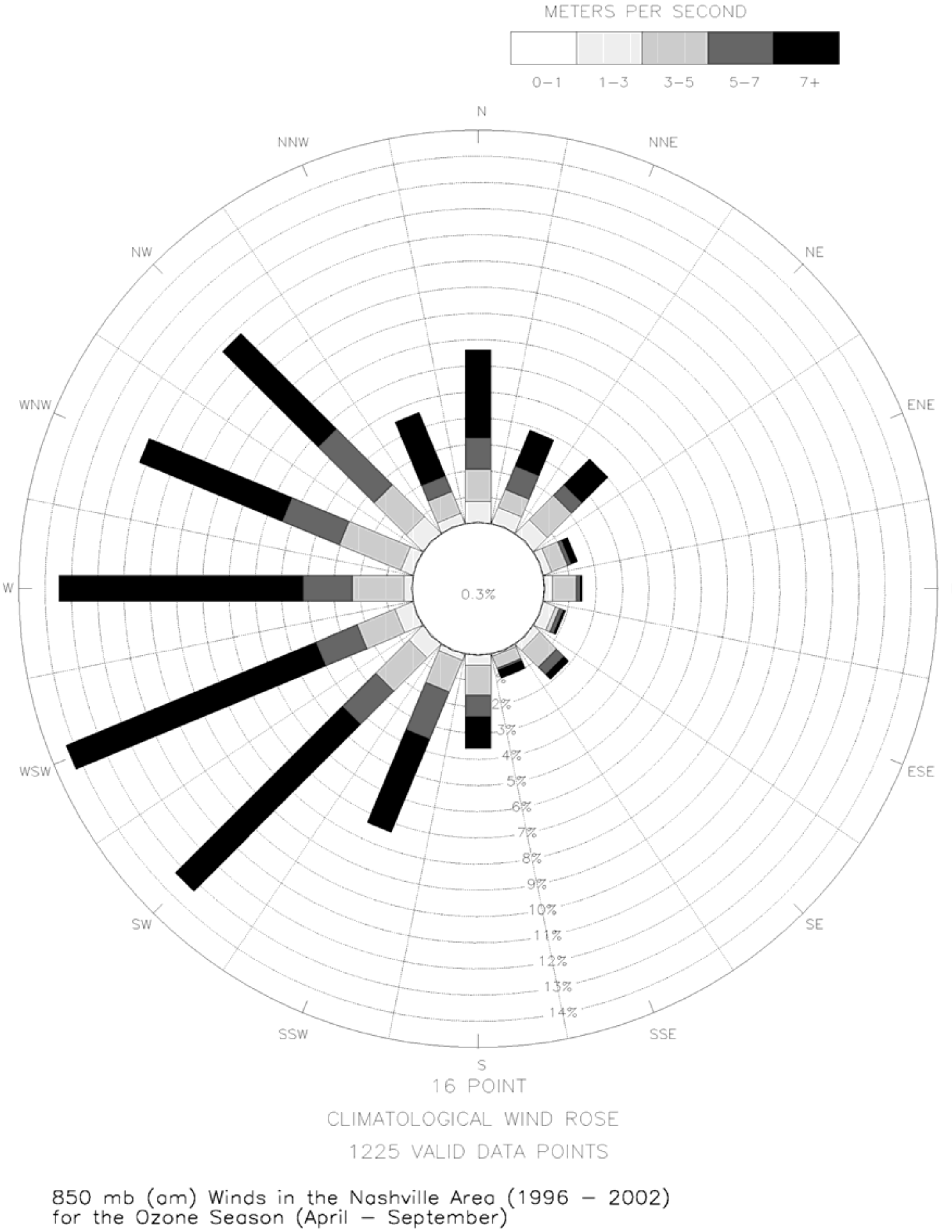


Figure 1-8b.
Winds at the 850 mb Level for the Nashville Sounding for the Ozone Season (April–October, 1996–2002): 1800 CST

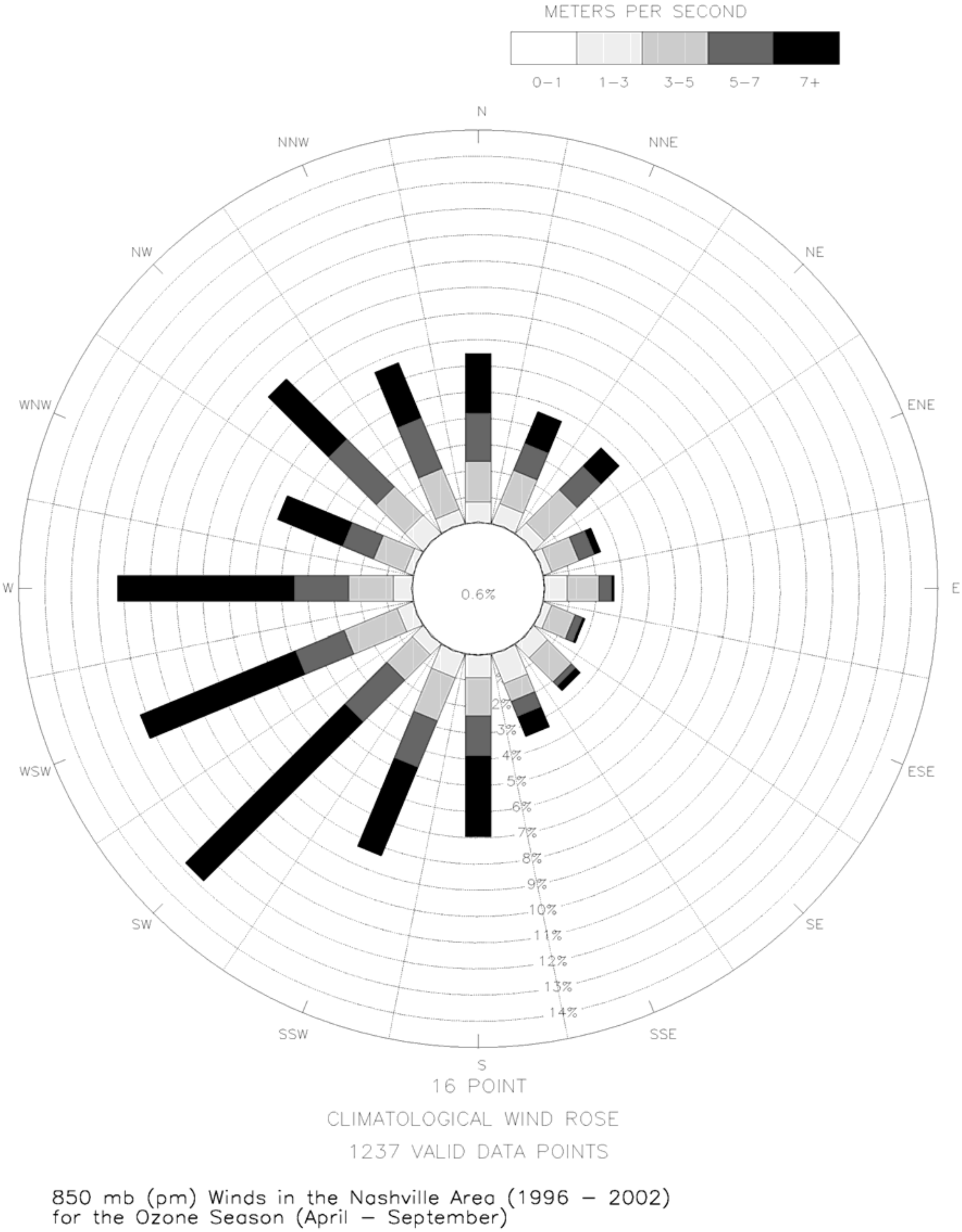


Figure 1-9a.
Winds at the 850 mb Level for the Nashville Sounding for 8-Hour Ozone Exceedance Days for Memphis (1996–2002): 0600 CST

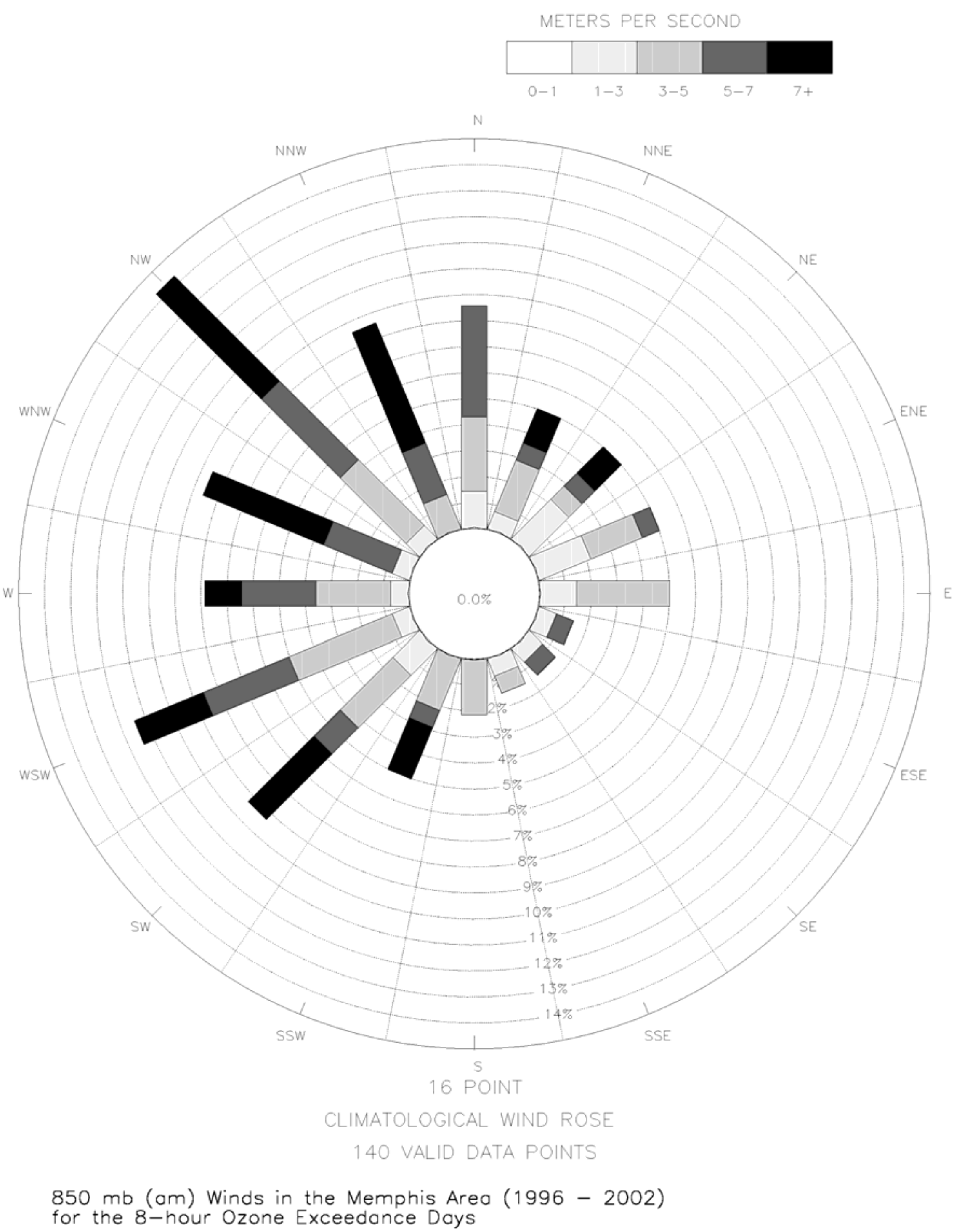


Figure 1-9b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Memphis (1996–2002): 1800 CST

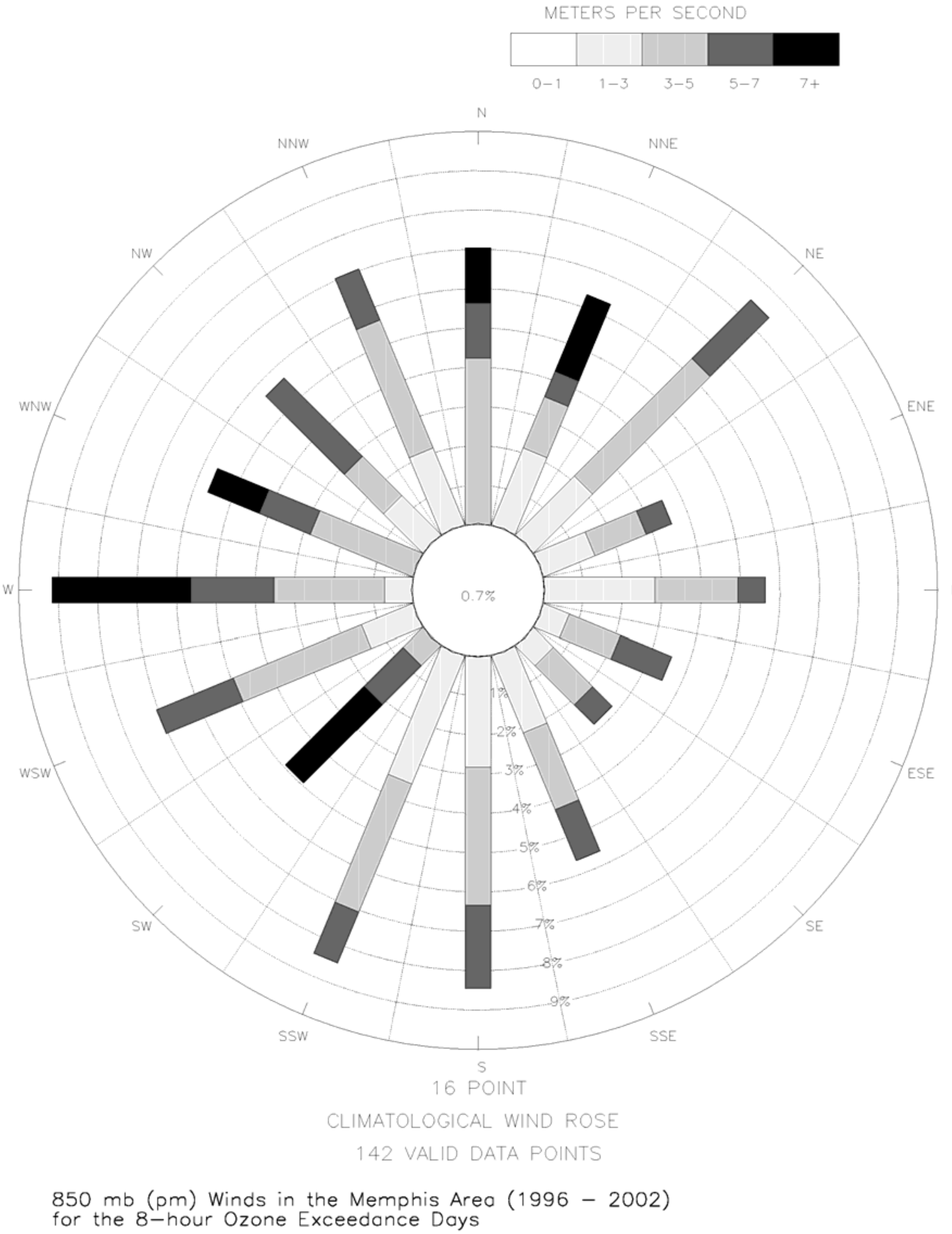


Figure 1-10a.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Nashville (1996–2002): 0600 CST

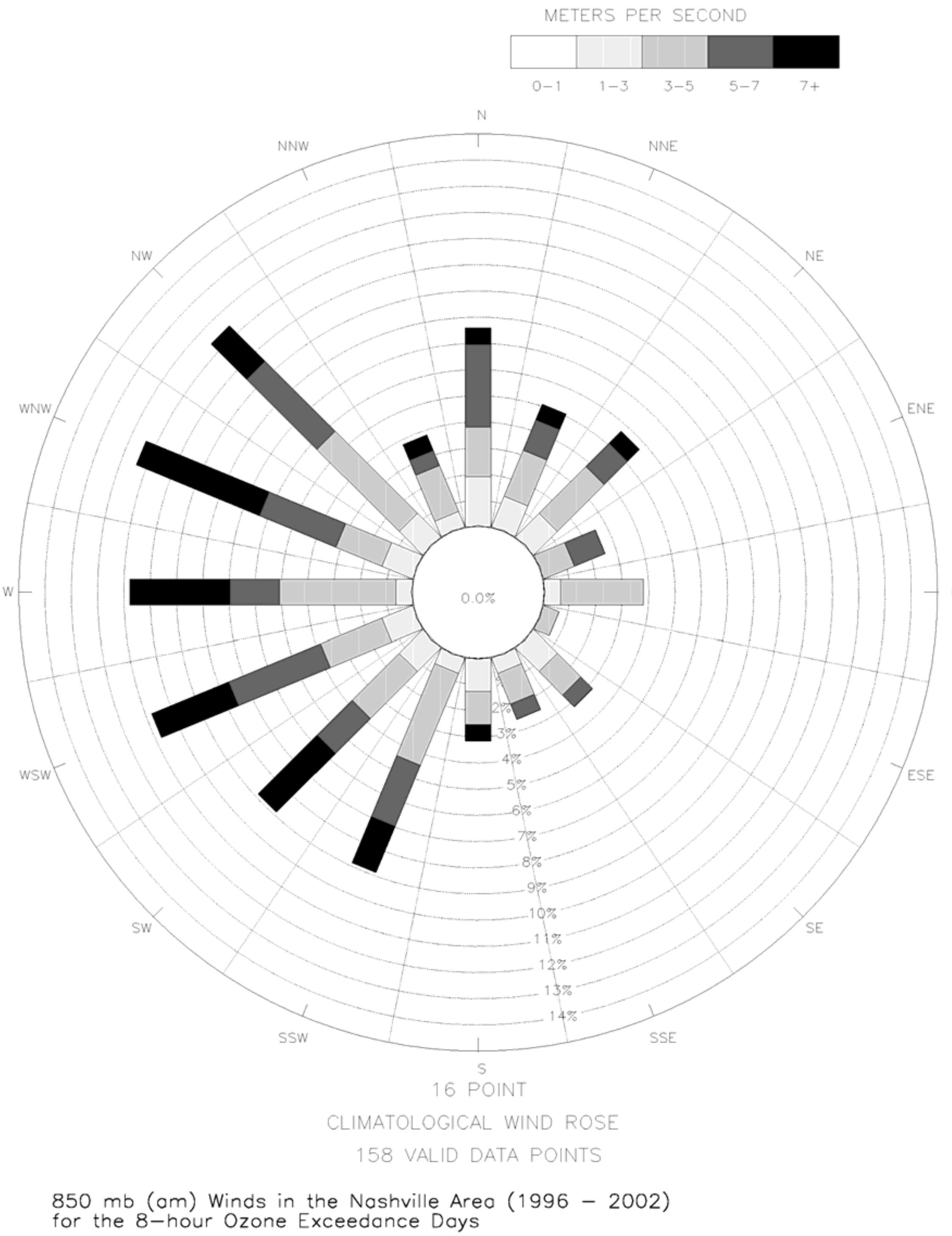
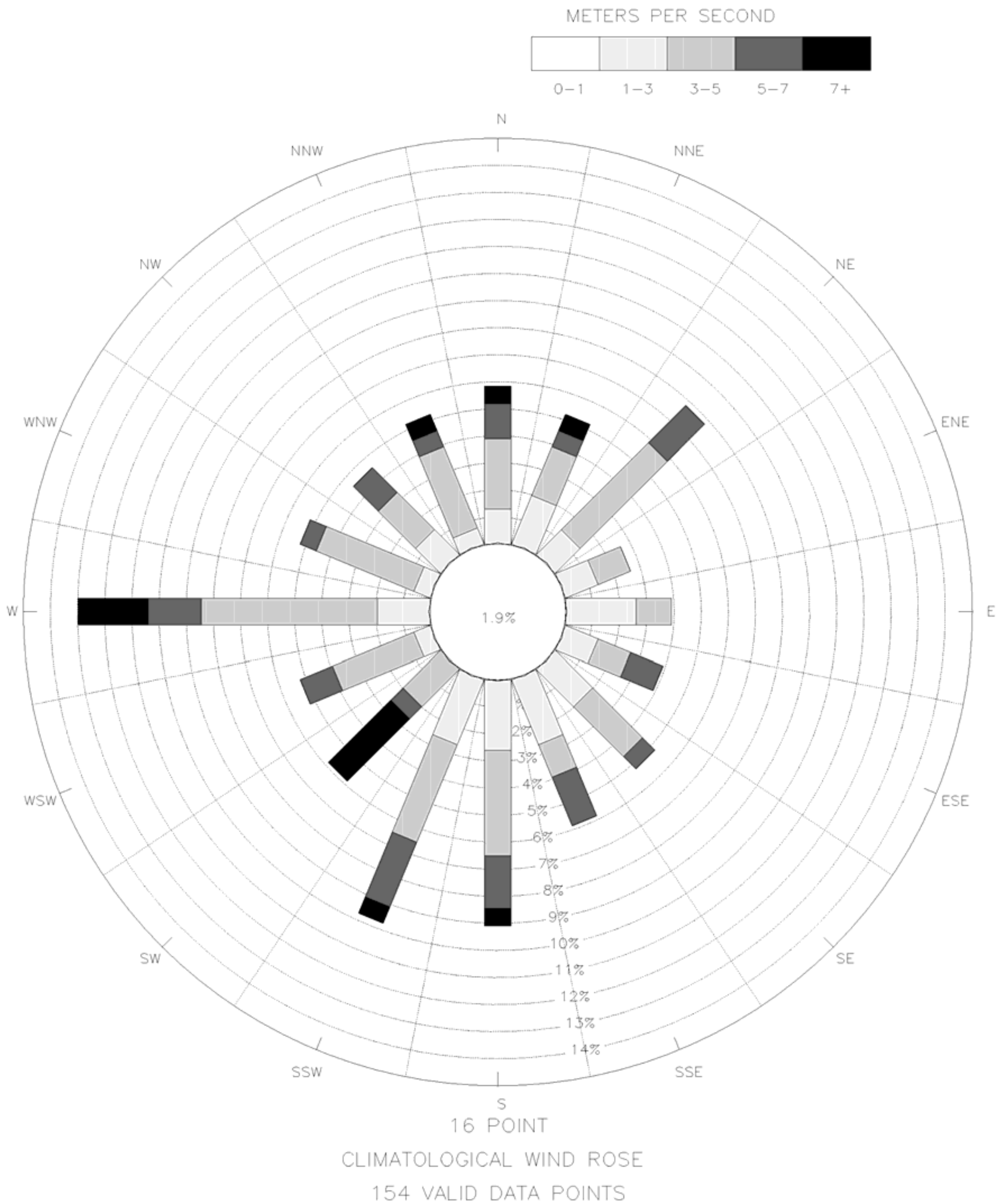
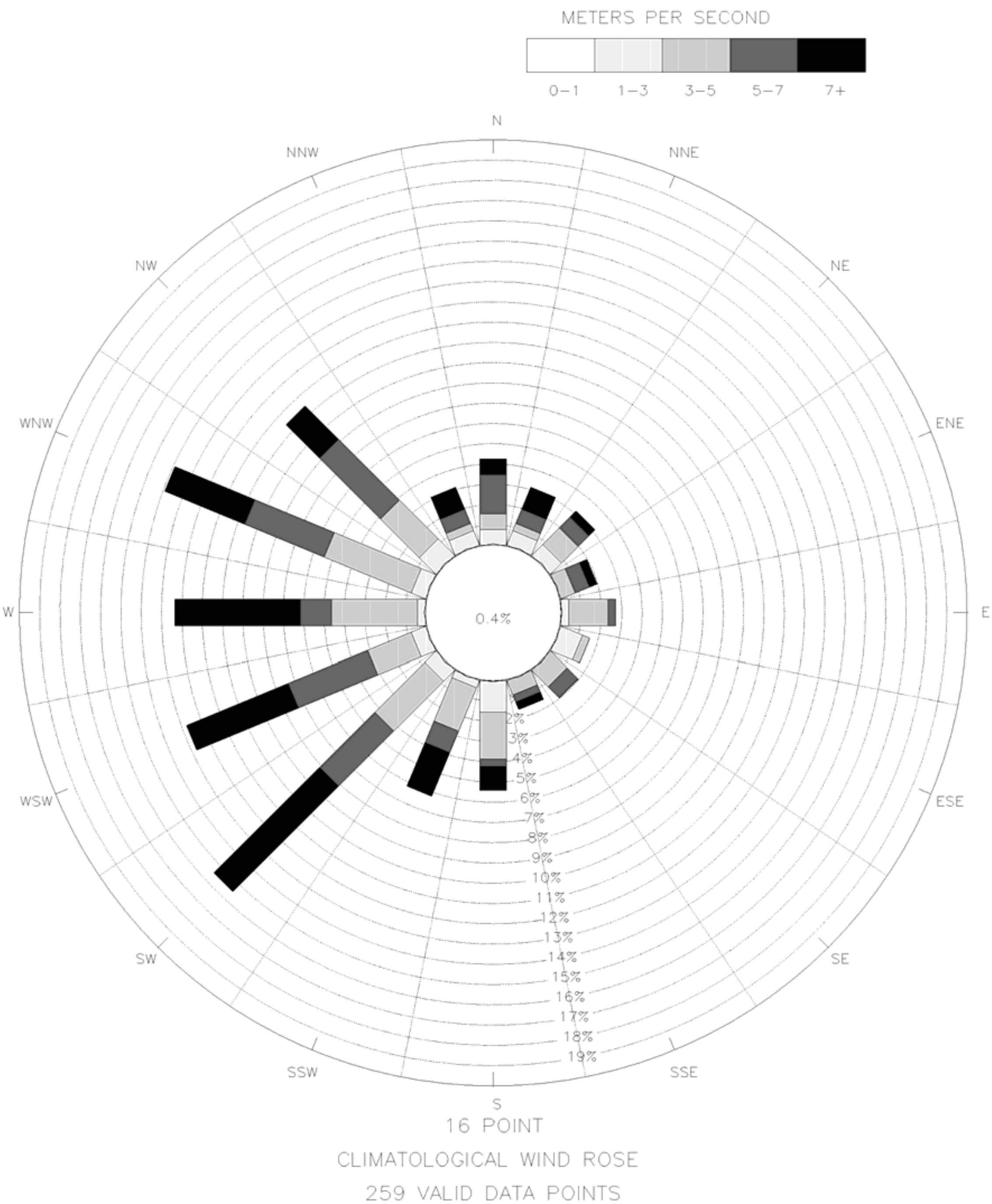


Figure 1-10b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Nashville (1996–2002): 1800 CST



850 mb (pm) Winds in the Nashville Area (1996 – 2002)
for the 8-hour Ozone Exceedance Days

Figure 1-11a.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Knoxville (1996–2002): 0600 CST



850 mb (am) Winds in the Knoxville Area (1996 – 2002)
for the 8–hour Ozone Exceedance Days

Figure 1-11b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Knoxville (1996–2002): 1800 CST

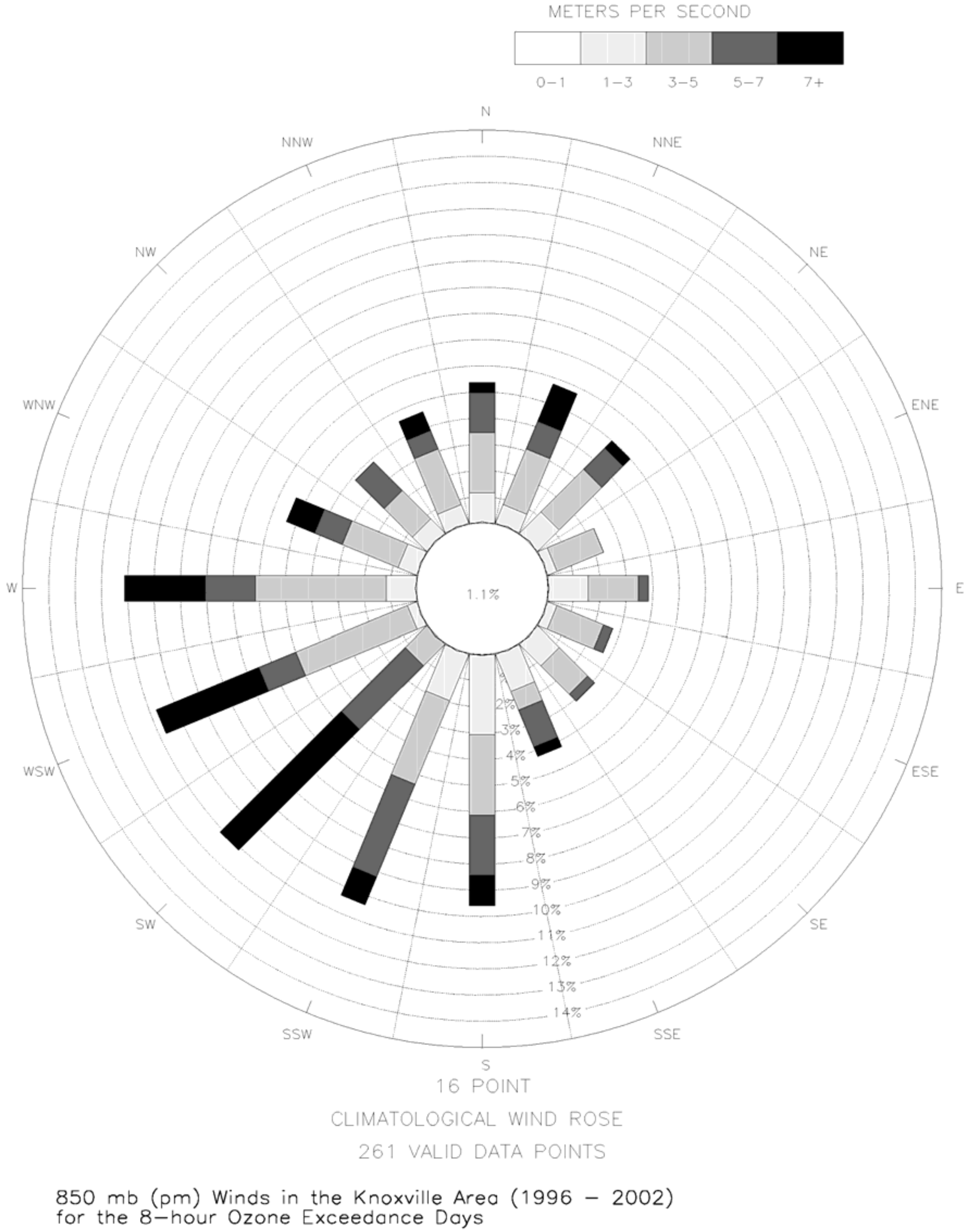


Figure 1-12a.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Chattanooga (1996–2002): 0600 CST

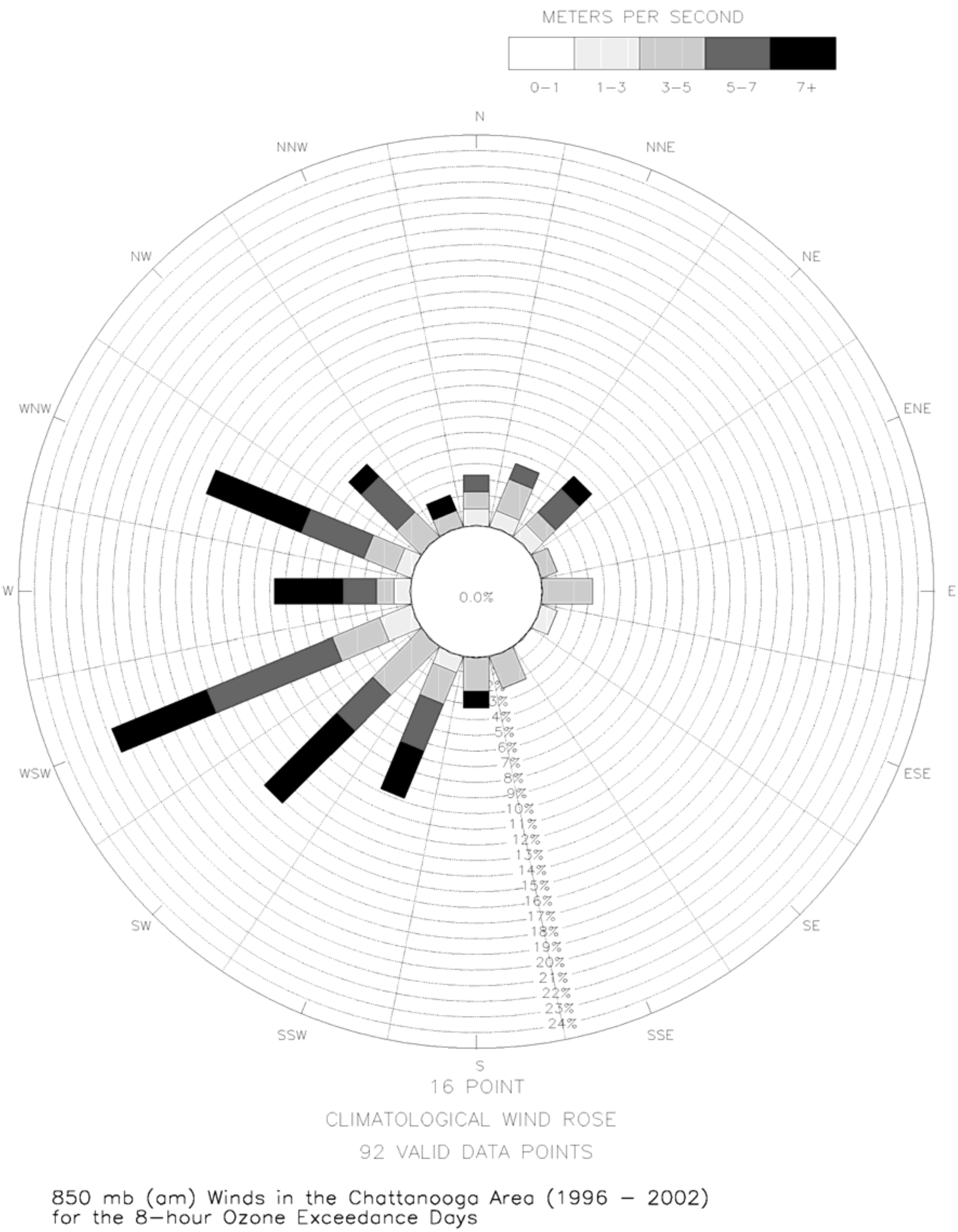
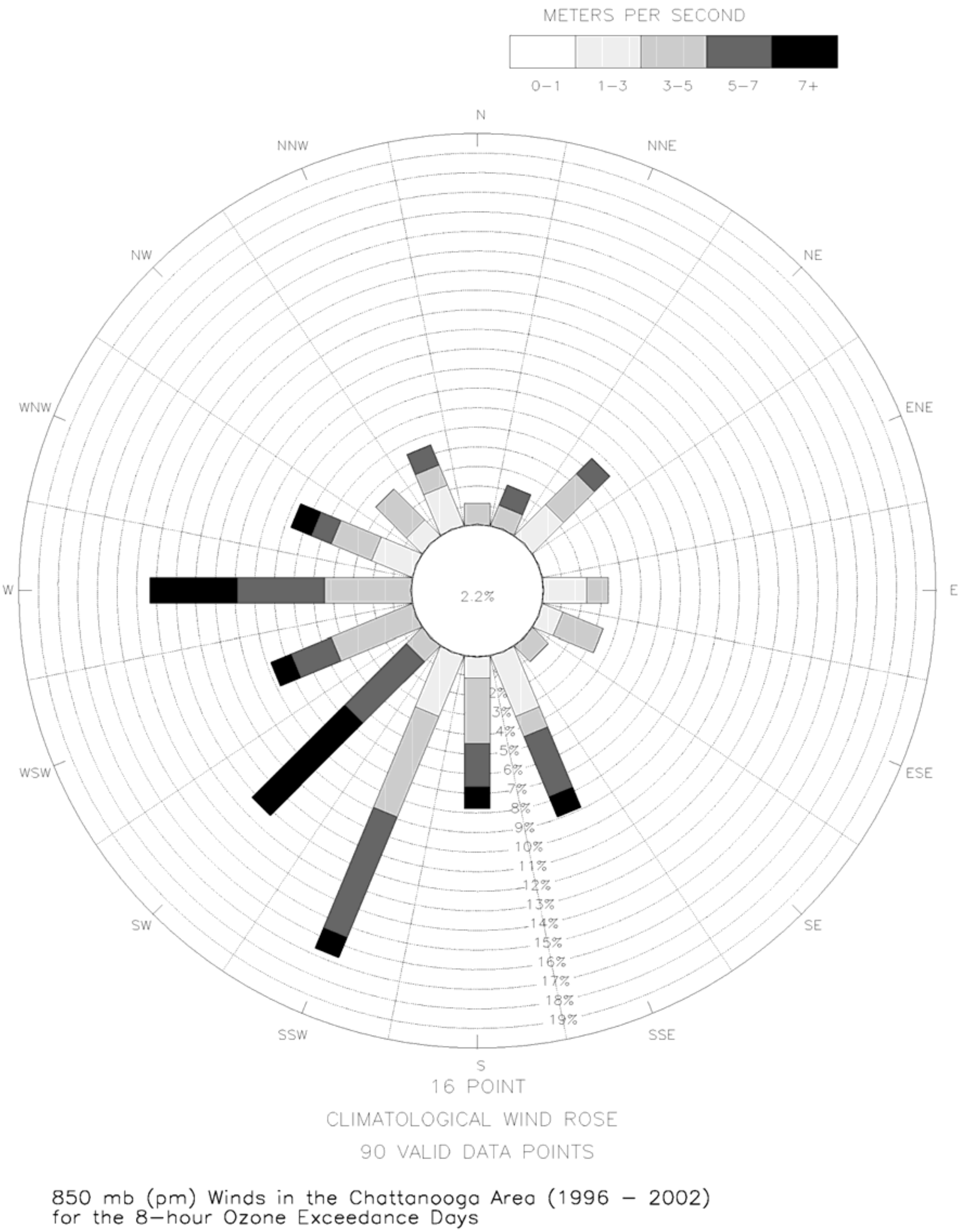


Figure 1-12b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Chattanooga (1996–2002): 1800 CST



CART-Based Analysis of Meteorological Factors

The factors that influence 8-hour ozone concentrations in the EAC areas were further examined using the results from an application of the Classification and Regression Tree (CART) analysis technique. CART (Brieman et al., 1984; Steinberg and Colla, 1997) is a statistical analysis tool that was used in the ATMOS episode selection analysis to classify all ozone season days for the years 1996-2002 according to meteorological and air quality parameters. The CART analysis software was used to separate the days into different groups (classification “bins”), such that days placed within the same bin exhibit similar meteorological features and ozone concentrations. For example, one bin may include high ozone days associated with low wind speeds, while another may include days with higher wind speeds, with transport indicated. The classification variable (for separating the days into bins) is maximum 8-hour ozone concentration. For ATMOS, CART was applied for the Memphis, Nashville, Knoxville, and Chattanooga areas, but not for the Tri-Cities area.

The results of the CART analysis take the form of an upside-down “tree,” with branches representing different values of the input variables, leading to bins representing different values of the classification variable (in this case, 8-hour ozone concentration). Each bin corresponds to a particular set of meteorological and ozone air quality conditions. By examining the parameters associated with each classification category, and specifically the parameters and parameter values used to segregate the days into the various classification bins, the analyst can gain insight into the key differences between exceedance days and non-exceedance days, and the mechanisms contributing to high ozone events. This information on the relationships between air quality and meteorology was used in developing the conceptual description of 8-hour ozone for each of the four areas.

MEMPHIS

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-6a. Table 1-6b considers the input parameter values for the Memphis key (most populated) ozone exceedance bins.

Table 1-6a
Summary of Input Parameters for Each CART Classification Category: Memphis

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Memphis (ppb)	55.3	70.5	80.5	82.8
Yesterday's maximum 8-hour ozone for Little Rock (ppb)	47.5	60.5	68.2	71.2
Surface Meteorological Parameters				
Maximum surface temperature (°F)	80.7	88.6	92.4	93.3
Surface relative humidity at noon (%)	60.9	49.8	45.3	45.2
Surface wind speed from 7-10 LST (ms^{-1})	3.9	2.9	2.3	2.0
Surface wind speed from 10-13 LST (ms^{-1})	4.5	3.7	2.7	1.7
Surface wind speed from 13-16 LST (ms^{-1})	4.6	3.9	3.0	2.1
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Maximum surface pressure (mb)	1018	1018	1018	1017
Upper-Air Meteorological Parameters (Little Rock)				
Yesterday's 850 mb temperature (PM) (°C)	14.9	17.4	18.7	18.9
850 mb temperature (AM) (°C)	14.4	16.7	18.3	18.1
850 mb temperature (PM) (°C)	14.7	17.7	19.4	19.1
Temperature gradient (900 mb to surface; AM) (°C)	-1.39	-0.92	-0.90	-0.74
850 mb relative humidity (AM) (%)	64.1	61.5	57.1	62.1
850 mb relative humidity (PM) (%)	66.8	63.6	60.3	61.7
850 mb geopotential height gradient between Nashville and Little Rock (m)	8.8	6.3	9.6	11.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.2	5.5	4.9	4.1
850 mb wind speed (AM) (ms^{-1})	9.5	6.1	4.8	4.9
850 mb wind speed (PM) (ms^{-1})	8.1	5.7	4.8	4.2
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	2
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	3

A column-by-column comparison of the values in Table 1-6a reveals some clear tendencies in several of the air quality and meteorological parameters.

High ozone in the Memphis area is associated with relatively high ozone on the prior day—in Memphis as well as in Little Rock. Thus, a regional day-to-day build up of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be southerly to westerly during the ozone season days included in the analysis. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters (based here on Little Rock) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is also a tendency for more stable (positive) lapse rates to be associated with higher ozone days. The difference in geopotential height (defined such that a positive number indicates higher heights (pressures) over Nashville) is somewhat correlated with higher ozone concentrations. The average difference is positive (in the range of 9 - 11 m) for the ozone exceedance days indicating higher pressure over Nashville.

Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations. The biggest jump in the wind speeds occurs between low and moderate ozone concentrations (Categories 1 and 2).

The information in table 1-6a provides a general overview of how average conditions vary across (and potentially lead to) different 8-hour ozone concentration levels for the Memphis area. Within the high ozone categories, there are other key differences among the parameters that result in different types of high ozone events. We have used the CART results to examine these differences.

Only certain of the CART bins are frequently associated with 8-hour ozone exceedances. Of these, we identified those bins with seven or more days (the equivalent of one day per year for the analysis period) as key bins. Table 1-6b considers the input parameter values for the Memphis key exceedance bins.

Table 1-6b.
Summary of Exceedance Bin Characteristics for the Memphis CART Analysis.

Bins 17, 25 and 30 are Category 3 CART bins

	Bin 17	Bin 25	Bin 30
Ozone Parameters			
Yesterday's maximum 8-hour ozone for Memphis (ppb)	80.2	72.7	68.4
Yesterday's maximum 8-hour ozone for Little Rock (ppb)	66.3	62.8	58.4
Surface Meteorological Parameters			
Maximum surface temperature (°F)	92.6	88.7	93.0
Surface relative humidity at noon (%)	43.6	44.2	46.0
Surface wind speed from 7-10 LST (ms^{-1})	2.0	2.1	2.7
Surface wind speed from 10-13 LST (ms^{-1})	2.2	2.6	1.9
Surface wind speed from 13-16 LST (ms^{-1})	2.7	4.6	3.7
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	2	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	2	3	4
Maximum surface pressure (mb)	1019	1019	1026
Upper-Air Meteorological Parameters (Little Rock)			
Yesterday's 850 mb temperature (PM) (°C)	18.4	18.0	18.2
850 mb temperature (AM) (°C)	17.8	16.7	16.0
850 mb temperature (PM) (°C)	18.9	17.5	16.8
Temperature gradient (900 mb to surface; AM) (°C)	-1.49	-1.34	-1.60
850 mb relative humidity (AM) (%)	62.3	63.3	89.6
850 mb relative humidity (PM) (%)	63.9	64.8	72.8
850 mb geopotential height gradient between Nashville and Little Rock (m)	12.0	4.4	13.5
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.4	5.3	4.6
850 mb wind speed (AM) (ms^{-1})	4.4	4.6	5.7
850 mb wind speed (PM) (ms^{-1})	3.7	5.4	5.7
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	2	2	4
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	3	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	4	4

Bins 17, 25 and 30 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

For Bin 17, a distinguishing characteristic is the relatively higher ozone concentrations on the previous day. Thus, for days within this bin, ozone builds up over multiple days. Surface winds tend to be lower than for the other exceedance bins, especially during the morning and late afternoon hours and surface winds tend to exhibit an easterly component. This same pattern is found in the winds aloft. The wind speeds tend to be lower than for the other exceedance bins and the directions are easterly to southerly.

For Bin 25, there is some regional-scale buildup of ozone and conditions are more stable than for the other bins. Surface winds are from the south, and moderate wind speeds characterize the afternoon hours. Weak pressure (height) gradients aloft and greater stability (compared to the other exceedance bins) also characterize the days within this bin. Winds aloft have a westerly component.

Days within Bin 30 are characterized by relatively low ozone on the prior day). Surface winds are from the south during the morning and then from the west during the afternoon hours. The wind speeds are in between those for the other two exceedance bins. High relative humidity aloft (indicative of some cloud cover) also characterizes this bin.

NASHVILLE

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-7a.

Table 1-7b considers the input parameter values for the Nashville key bins.

Table 1-7a.
Summary of Input Parameters for Each CART Classification Category: Nashville

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Nashville (ppb)	56.0	70.1	83.4	92.6
Surface Meteorological Parameters				
Maximum surface temperature (°F)	77.4	85.4	90.6	91.4
Surface relative humidity at noon (%)	62.4	49.7	46.6	41.6
Surface wind speed from 7-10 LST (ms^{-1})	3.2	2.2	1.6	1.0
Surface wind speed from 10-13 LST (ms^{-1})	3.9	3.4	2.4	2.3
Surface wind speed from 13-16 LST (ms^{-1})	4.2	3.7	2.9	2.3
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	1	3
Maximum surface pressure (mb)	1018	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	13.5	15.3	17.7	18.0
850 mb temperature (AM) (°C)	12.5	14.8	17.1	17.7
850 mb temperature (PM) (°C)	13.0	15.9	18.6	19.3
Temperature gradient (900 mb to surface; AM) (°C)	-1.06	0.36	1.3	3.3
850 mb relative humidity (AM) (%)	73.3	65.6	62.5	52.2
850 mb relative humidity (PM) (%)	73.2	68.7	65.3	58.4
Change in the 850 mb geopotential height (today – yesterday) (m)	-2.1	1.6	2.3	-1.2
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.6	5.8	4.2	3.4
850 mb wind speed (AM) (ms^{-1})	9.8	7.1	5.1	4.7
850 mb wind speed (PM) (ms^{-1})	8.4	6.0	4.1	3.6
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4

High ozone days in the Nashville area are associated with relatively high ozone on the prior day. Thus, a day-to-day build up or carryover of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be southerly to westerly during the ozone season days included in the analysis. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters for Nashville indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is a strong positive correlation between the 900 mb to surface temperature difference (an indicator of stability) and ozone category, with very stable conditions indicated for the highest category. Relative humidity aloft, an indicator of cloud cover, decreases with increasing ozone. Lower wind speeds aloft are also aligned with higher 8-hour ozone concentrations. There is no clear tendency in average wind direction aloft (note that this finding is consistent with the wind rose diagrams presented earlier in this section).

Table 1-7b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-7b.
Summary of Exceedance Bin Characteristics for the Nashville CART Analysis.

Bins 7, 18, 20, and 34 are Category 3 CART bins and Bin 26 is a Category 4 CART bin.

	Bin 7	Bin 18	Bin 20	Bin 34	Bin 26
Ozone Parameters					
Yesterday's maximum 8-hour ozone for Nashville (ppb)	67.4	65.9	67.1	62.4	91.6
Surface Meteorological Parameters					
Maximum surface temperature (°F)	89.4	89.5	90.0	77.3	92.1
Surface relative humidity at noon (%)	47.1	50.4	51.4	34.3	38.4
Surface wind speed from 7-10 LST (ms^{-1})	1.2	2.0	1.7	3.4	1.0
Surface wind speed from 10-13 LST (ms^{-1})	2.3	4.0	2.8	5.1	2.3
Surface wind speed from 13-16 LST (ms^{-1})	2.9	3.6	3.3	5.3	2.7
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	2	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	2	1	4	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	2	1	3	2	4
Maximum surface pressure (mb)	1020	1017	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)					
Yesterday's 850 mb temperature (PM) (°C)	16.7	17.1	17.6	10.3	18.2
850 mb temperature (AM) (°C)	16.7	16.7	16.4	9.6	17.7
850 mb temperature (PM) (°C)	17.9	18.0	18.1	11.5	19.1
Temperature gradient (900 mb to surface; AM) (°C)	0.93	0.71	-0.02	0.63	3.8
850 mb relative humidity (AM) (%)	52.2	56.4	84.4	46.8	55.5
850 mb relative humidity (PM) (%)	68.1	69.2	74.4	51.6	60.8
Change in the 850 mb geopotential height (today – yesterday) (m)	15.2	0.9	3.3	4.5	-4.7
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.7	5.7	4.6	8.4	3.4
850 mb wind speed (AM) (ms^{-1})	4.9	6.7	5.2	12.0	4.6
850 mb wind speed (PM) (ms^{-1})	3.9	4.7	4.1	11.3	3.8
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	1	4	3	1	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	1	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	1	4	3	3

Bins 7, 18, 20, and 34 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bind 26 is a Category 4 bin, which corresponds to the highest CART concentration range of greater than 104 ppb. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

Bins 7, 18 and 20 have similar average values for previous day ozone concentration, maximum surface temperature and temperature aloft, surface relative humidity, and stability. There are differences, however, in wind speed and direction, both near the surface and aloft. Surface winds for Bin 7 are from the east and wind speeds are low. For this same bin, the upper air winds are primarily westerly to southerly and wind speeds are moderate. For Bin 18, surface winds are from the north with low to moderate wind speeds. Winds aloft are moderate and westerly to northerly. Bin 20 is characterized by westerly to southerly surface winds, with low to moderate wind speeds (lower than for Bin 18) and moderate westerly winds aloft. Thus, these three bins are likely to capture different source-receptor relationships. Another different among these bins is the average relative humidity aloft – high values for Bin 20 indicate cloud cover. The change in geopotential height is also very different for the three bins.

Bin 34 has very different characteristics overall. Days within this bin are characterized by much lower temperatures and stronger wind speeds that the other exceedance days. Winds aloft are from the north, while surface winds are from the southeast. Days within this bin are representative of transitional period (spring or fall) high ozone days.

Days within Bin 26 (the Category 4 bin) are characterized by very high ozone on the prior day. Temperatures (both the near the surface and aloft) are higher than for the other bins, while relative humidity is low. Stable lapse rates are also indicated and distinguish this bin from the other exceedance bins. Relatively low wind speeds near the surface and aloft and southerly to westerly winds round out the characteristics of this bin.

KNOXVILLE

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-8a.

Table 1-8b considers the input parameter values for the Knoxville key bins.

Table 1-8a.
Summary of Input Parameters for Each CART Classification Category: Knoxville

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Knoxville (ppb)	62.0	73.5	87.6	99.3
Yesterday's maximum 8-hour ozone for Nashville (ppb)	51.3	66.1	80.3	89.0
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	46.6	60.3	75.0	82.9
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	51.6	69.2	89.1	96.8
Surface Meteorological Parameters				
Maximum surface temperature (°F)	74.5	81.8	88.0	90.1
Surface relative humidity at noon (%)	67.6	58.7	52.9	50.9
Surface wind speed from 7-10 LST (ms^{-1})	2.9	1.9	1.3	0.9
Surface wind speed from 10-13 LST (ms^{-1})	3.9	3.0	2.4	1.4
Surface wind speed from 13-16 LST (ms^{-1})	4.2	3.7	3.1	2.3
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	1	1	2
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	4	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	4	4
Maximum surface pressure (mb)	1018	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	12.7	14.8	17.6	18.4
850 mb temperature (AM) (°C)	11.5	14.1	16.9	17.8
850 mb temperature (PM) (°C)	11.9	15.2	18.1	18.9
Temperature gradient (900 mb to surface; AM) (°C)	-1.45	-0.11	1.15	2.14
850 mb relative humidity (AM) (%)	73.9	68.7	63.2	60.0
850 mb relative humidity (PM) (%)	72.8	70.6	66.9	68.2
850 mb geopotential height gradient between Greensboro and Nashville (m)	1.9	1.1	-3.9	-4.3
Yesterday's 850 mb wind speed (PM) (ms^{-1})	9.2	6.7	4.5	4.0
850 mb wind speed (AM) (ms^{-1})	10.0	8.1	6.0	5.3
850 mb wind speed (PM) (ms^{-1})	8.3	7.0	5.1	4.5
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3

High ozone in the Knoxville area is associated with the regional day-to-day build up of ozone.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. For all of these parameters, good correlation is indicated. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be westerly during the ozone season days included in the analysis. Average surface pressure does not vary across the classification categories.

The upper-air meteorological parameters (based here on Nashville) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is also a very clear tendency for more stable (positive) lapse rates to be associated with higher ozone days. The difference in geopotential height between Greensboro and Nashville (defined such that a positive number indicates higher heights (pressures) over Greensboro) indicates that high ozone occurs with higher pressure over Nashville.

Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations.

Table 1-8b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-8b.
Summary of Exceedance Bin Characteristics for the Knoxville CART Analysis.

Bins 10, 16, 23, and 29 are Category 3 CART bins and Bin 27 is a Category 4 CART bin.

	Bin 10	Bin 16	Bin 23	Bin 29	Bin 27
Ozone Parameters					
Yesterday's maximum 8-hour ozone for Knoxville (ppb)	74.0	73.4	73.2	68.5	107.6
Yesterday's maximum 8-hour ozone for Nashville (ppb)	73.4	73.7	71.6	65.2	90.0
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	65.6	60.1	60.0	56.7	87.8
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	81.5	80.7	77.4	65.8	99.6
Surface Meteorological Parameters					
Maximum surface temperature (°F)	88.3	88.4	87.9	73.6	90.4
Surface relative humidity at noon (%)	55.9	58.2	62.8	89.2	50.8
Surface wind speed from 7-10 LST (ms^{-1})	1.5	1.6	1.7	2.0	1.0
Surface wind speed from 10-13 LST (ms^{-1})	2.5	2.1	2.7	2.9	1.6
Surface wind speed from 13-16 LST (ms^{-1})	3.1	3.2	3.2	3.2	2.4
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	4	2	1	2
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	2	4	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	1	4	4
Maximum surface pressure (mb)	1018	1018	1017	1016	1019
Upper-Air Meteorological Parameters (Nashville)					
Yesterday's 850 mb temperature (PM) (°C)	17.4	19.1	18.1	14.7	18.9
850 mb temperature (AM) (°C)	17.5	18.3	16.8	13.6	17.8
850 mb temperature (PM) (°C)	18.3	19.2	18.2	13.7	19.0
Temperature gradient (900 mb to surface; AM) (°C)	0.96	-0.53	-0.66	-1.31	2.3
850 mb relative humidity (AM) (%)	57.6	64.3	89.3	83.1	65.1
850 mb relative humidity (PM) (%)	73.3	71.6	75.6	75.6	67.9
850 mb geopotential height gradient between Greensboro and Nashville (m)	-5.5	-14.1	-3.9	10.6	2.0
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.6	5.7	5.2	7.7	4.2
850 mb wind speed (AM) (ms^{-1})	6.7	6.4	6.1	10.0	5.8
850 mb wind speed (PM) (ms^{-1})	5.5	4.8	5.2	8.2	5.0
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	4	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	4	4

Bins 10, 16, 23 and 29 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bin 27 is a Category 4 bin with concentrations greater than 105 ppb (for correctly classified days). While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin. The characteristics of and the differences among the bins is reminiscent of those for Nashville.

Bins 10, 16 and 23 have similar average values for previous day ozone concentration, maximum surface temperature, surface relative humidity, wind speed, and 900 mb to surface lapse rate. Bins 10 and 16 share similar wind characteristics, but Bin 16 shows a greater pressure differential between Greensboro and Nashville, with higher pressure over Nashville and higher 850 mb temperatures (likely the result of being under the influence of a high pressure system). Bins 10 and 23 have similar pressure differential and 850 mb temperatures, but Bin 23 differs from both Bins 10 and 16 in that the surface winds are from the east or north, rather than from the west. Winds aloft also have a southerly component during the afternoon hours, that is not indicate for the other two bins. Thus, these three bins represent three different combinations of two sets of vertical mixing characteristics and two different source-receptor relationships.

Bin 29 has very different characteristics overall. Days within this bin are characterized by lower ozone concentrations on the prior day, much lower temperatures, and stronger wind speeds that the other exceedance days. Winds aloft are from the west, while surface winds are from the north and west. Days within this bin are representative of transitional period (spring or fall) high ozone days.

Days within Bin 27 (the Category 4 bin) are characterized by very high ozone on the prior day. Temperatures (both the near the surface and aloft) are higher than for the other bins, while relative humidity is low. Stable lapse rates are also indicated and distinguish this bin from the other exceedance bins. Relatively low wind speeds near the surface and aloft and predominantly westerly winds round out the characteristics of this bin.

CHATTANOOGA

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-9a.

Table 1-9b considers the input parameter values for the Chattanooga key bins.

Table 1-9a.
Summary of Input Parameters for Each CART Classification Category: Chattanooga

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	52.5	68.6	81.9	90.1
Yesterday's maximum 8-hour ozone for Nashville (ppb)	57.4	75.3	84.3	94.7
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	59.6	80.4	91.6	106.4
Yesterday's maximum 8-hour ozone for Birmingham (ppb)	50.9	68.6	82.0	88.0
Surface Meteorological Parameters				
Maximum surface temperature (°F)	80.0	87.8	91.2	92.8
Surface relative humidity at noon (%)	61.8	50.9	46.3	43.3
Surface wind speed from 7-10 LST (ms^{-1})	1.8	1.0	0.6	0.2
Surface wind speed from 10-13 LST (ms^{-1})	3.0	2.3	1.7	1.0
Surface wind speed from 13-16 LST (ms^{-1})	3.6	3.0	2.5	2.6
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	1
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	3
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Maximum surface pressure (mb)	1018	1019	1020	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	13.7	16.1	17.6	18.2
850 mb temperature (AM) (°C)	12.7	15.6	17.0	17.9
850 mb temperature (PM) (°C)	13.3	16.8	18.5	19.1
Temperature gradient (900 mb to surface; AM) (°C)	-1.02	0.79	2.11	3.87
850 mb relative humidity (AM) (%)	72.3	63.8	60.6	55.3
850 mb relative humidity (PM) (%)	72.4	67.6	64.5	59.9
850 mb geopotential height gradient between Greensboro and Nashville (m)	1.6	-1.5	-5.1	-1.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.2	5.2	4.2	3.9
850 mb wind speed (AM) (ms^{-1})	9.4	6.6	5.8	5.0
850 mb wind speed (PM) (ms^{-1})	7.8	5.9	4.7	4.9
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	4

High ozone in the Chattanooga area is associated with relatively high ozone on the prior day—throughout the region. Thus, day-to-day build up or carryover of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. The differences between the Category 3 and 4 averages for surface temperature and wind speed are not as clear as for the other areas. Southerly surface wind directions are associated with the higher ozone categories. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters (based here on Nashville) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is a clear a tendency for more stable (positive) lapse rates to be associated with higher ozone days. Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations. The biggest jump in the wind speeds occurs between low and moderate ozone concentrations (Categories 1 and 2).

Table 1-8b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-9b.
Summary of Exceedance Bin Characteristics for the Chattanooga CART Analysis.
Bins 23 and 33 are Category 3 CART bins and Bin 26 is a Category 4 CART bin.

	Bin 23	Bin 33	Bin 26
Ozone Parameters			
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	84.5	92.3	89.0
Yesterday's maximum 8-hour ozone for Nashville (ppb)	78.7	94.8	89.2
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	86.9	112.5	90.6
Yesterday's maximum 8-hour ozone for Birmingham (ppb)	81.6	91.6	80.7
Surface Meteorological Parameters			
Maximum surface temperature (°F)	87.9	94.2	92.5
Surface relative humidity at noon (%)	50.9	44.1	43.1
Surface wind speed from 7-10 LST (ms^{-1})	0.5	0.1	0.6
Surface wind speed from 10-13 LST (ms^{-1})	1.4	1.3	1.9
Surface wind speed from 13-16 LST (ms^{-1})	2.1	3.0	2.9
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	2	4
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	4	3
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	3	4	4
Maximum surface pressure (mb)	1020	1018	1020
Upper-Air Meteorological Parameters (Nashville)			
Yesterday's 850 mb temperature (PM) (°C)	15.2	19.0	18.9
850 mb temperature (AM) (°C)	15.2	18.8	17.6
850 mb temperature (PM) (°C)	16.6	19.8	18.8
Temperature gradient (900 mb to surface; AM) (°C)	2.22	4.26	1.82
850 mb relative humidity (AM) (%)	64.4	55.5	63.9
850 mb relative humidity (PM) (%)	66.5	58.6	61.4
850 mb geopotential height gradient between Greensboro and Nashville (m)	-3.2	-3.8	-10.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	5.0	4.0	4.0
850 mb wind speed (AM) (ms^{-1})	6.7	5.2	6.0
850 mb wind speed (PM) (ms^{-1})	5.4	4.9	4.7
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	3	2
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	4	4

Bins 23 and 33 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bin 26 is a Category 4 bin, with higher ozone concentrations. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

Bin 23 is described by moderate ozone levels on the prior day, very light surface winds from the south, and moderate winds aloft from the west and south.

Interestingly, Bin 33, a Category 3 bin, is associated with the highest prior day average ozone concentrations among the three bins. It also exhibits the highest surface temperatures and the greatest stability. Surface winds tend to be lower than for the other exceedance bins, especially during the morning and early afternoon hours and are primarily westerly. Moderate upper-air winds, also from the west characterize this bin, but with winds from the south on the previous evening.

For Bin 26 falls between these two bins, considering the average values of most of the parameters. The height difference from Greensboro to Nashville is more negative, indicating a stronger west to east pressure gradient over the area. Easterly winds aloft on the previous evening and southerly winds near the surface on during the mid-afternoon hours may also contribute to the differences in observed ozone for days within this bin.

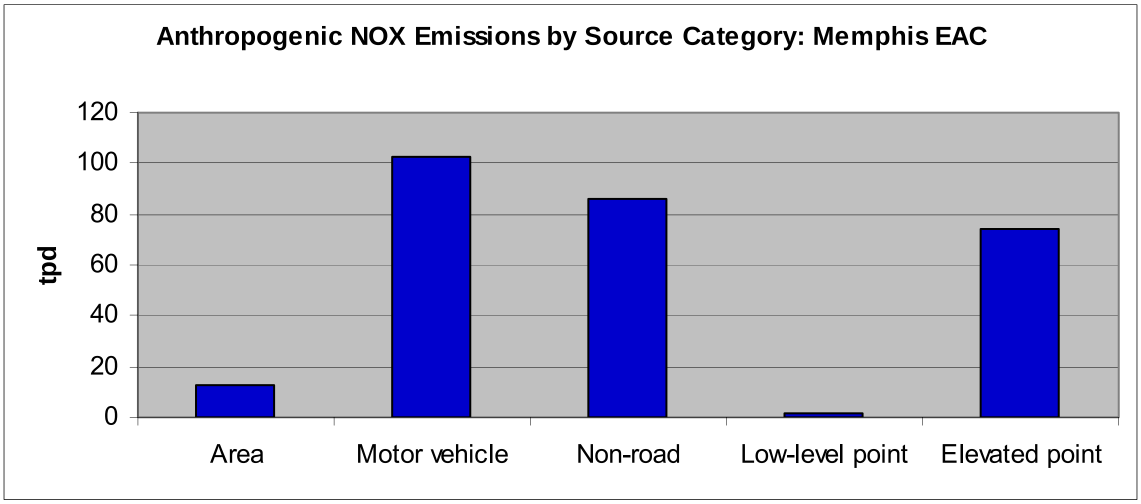
Emissions Influencing Ozone Within the ATMOS Region

All of the ATMOS EAC areas are located in the mid-South portion of the continental U.S. Regional-scale modeling results performed by EPA (e.g., EPA, 2004) as well as the ATMOS regional modeling results presented later in this report indicate that ozone concentrations in this region are influenced by ozone and precursor transport from outside of the region. Emission source areas to the north, east, west, and south including major metropolitan areas to the northeast, north, northwest, southwest, and south of the domain ensure the potential for a contribution from regional-scale transport. As indicated in a previous section, ozone episodes are associated with a variety of upper-level wind directions and, thus, a range of potential transport conditions.

Within the region, there are numerous sources of NO_x, VOC, and CO emissions that likely also contribute to ozone production in the region and affect one or more of the EAC areas. Ozone precursor emissions from anthropogenic sources are the result of activity associated with transportation (both interstate and local), electrical generation, manufacturing/industry, and other population-related sources (household products, home heating, recreational equipment, etc.). A number of electrical generation stations, chemical and petrochemical industry sources, and gas compressor stations are located in the region. In addition, other sources such as barge and commercial shipping traffic along the Mississippi River, and furniture manufacturing facilities contribute to the emissions totals in specific portions of the region.

Plots of the anthropogenic NO_x and VOC emissions by source category are presented for each EAC region in Figure 1-13. In general, large sources of NO_x include electric generation, other industrial boilers, and mobile sources. The anthropogenic VOC emissions originate from a variety of area, industrial, and transportation-related sources.

Figure 1-13a.
Weekday Anthropogenic Emissions (tpd) in the Memphis EAC Area by Species and Source Category



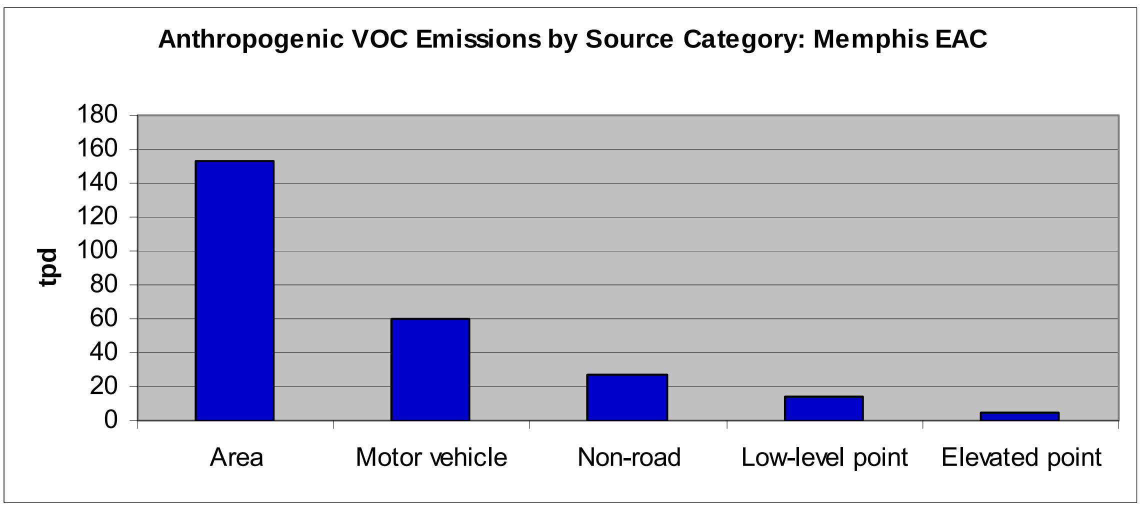
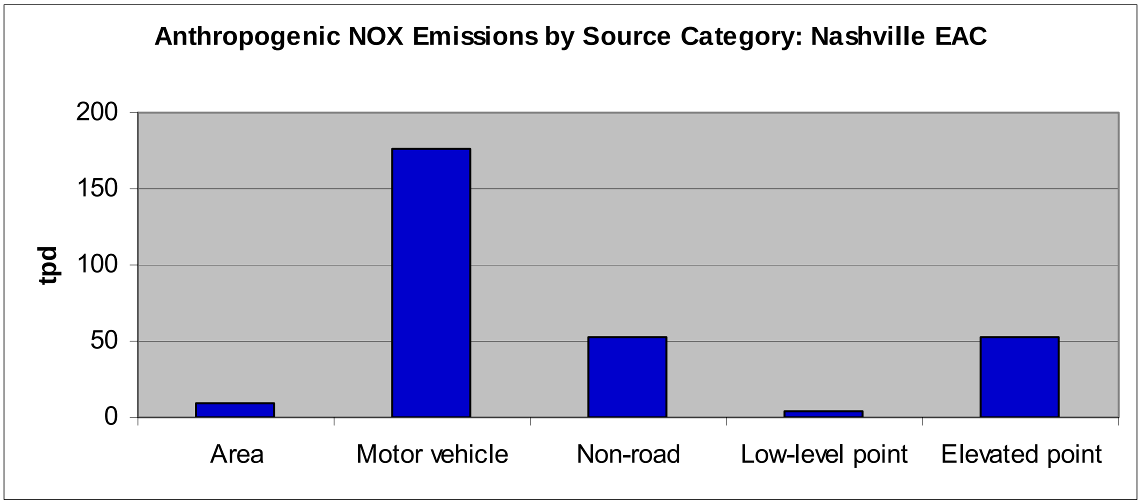


**Figure 1-13b.
Weekday Anthropogenic Emissions (tpd) in the Nashville EAC Area
by Species and Source Category**



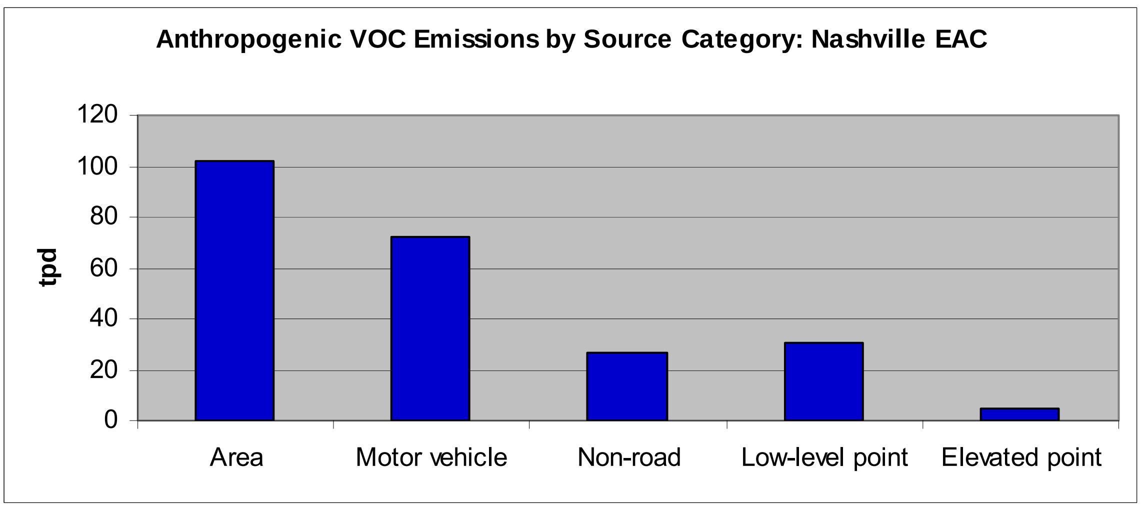
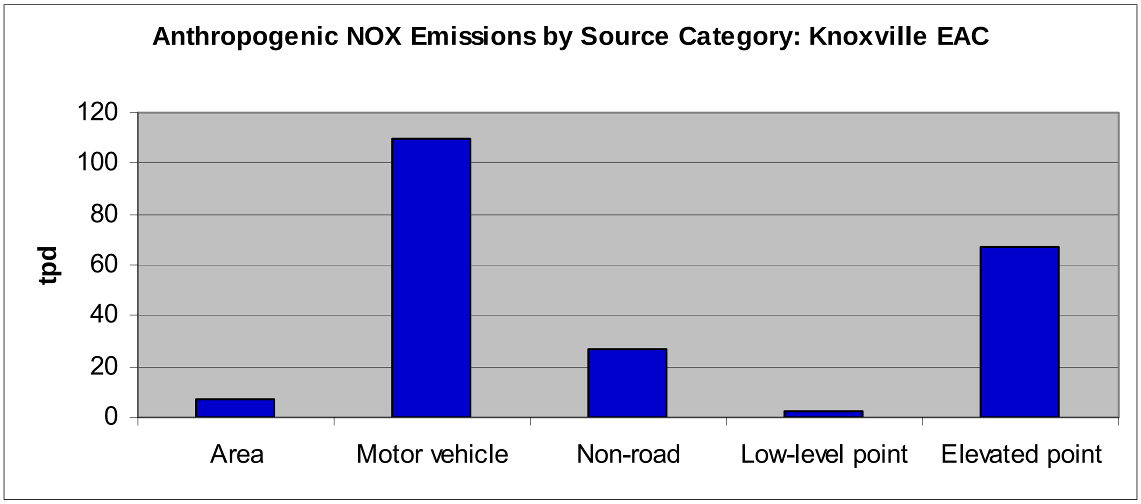


Figure 1-13c.
Weekday Anthropogenic Emissions (tpd) in the Knoxville EAC Area by Species and Source Category



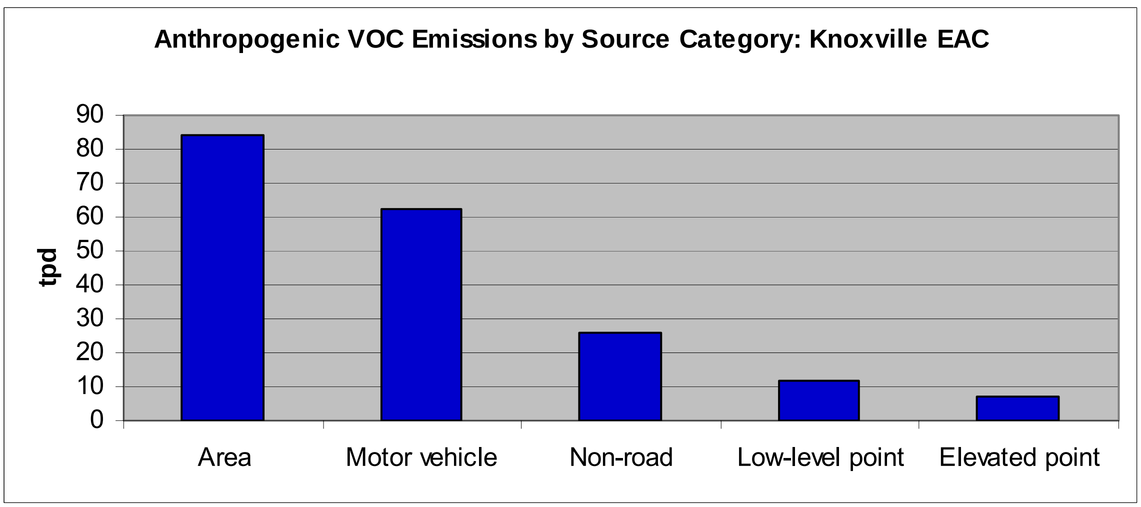
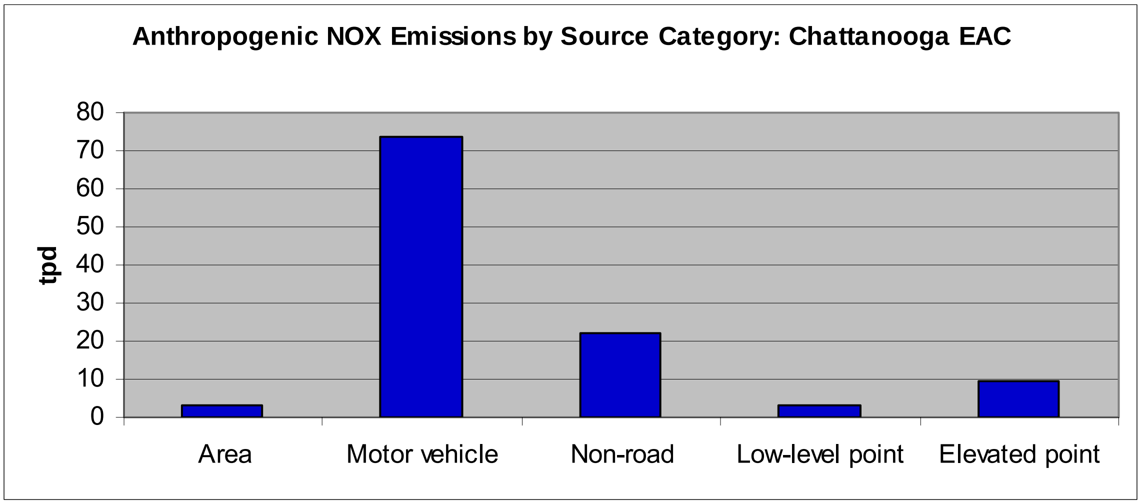


Figure 1-13d.
Weekday Anthropogenic Emissions (tpd) in the Chattanooga EAC Area by Species and Source Category



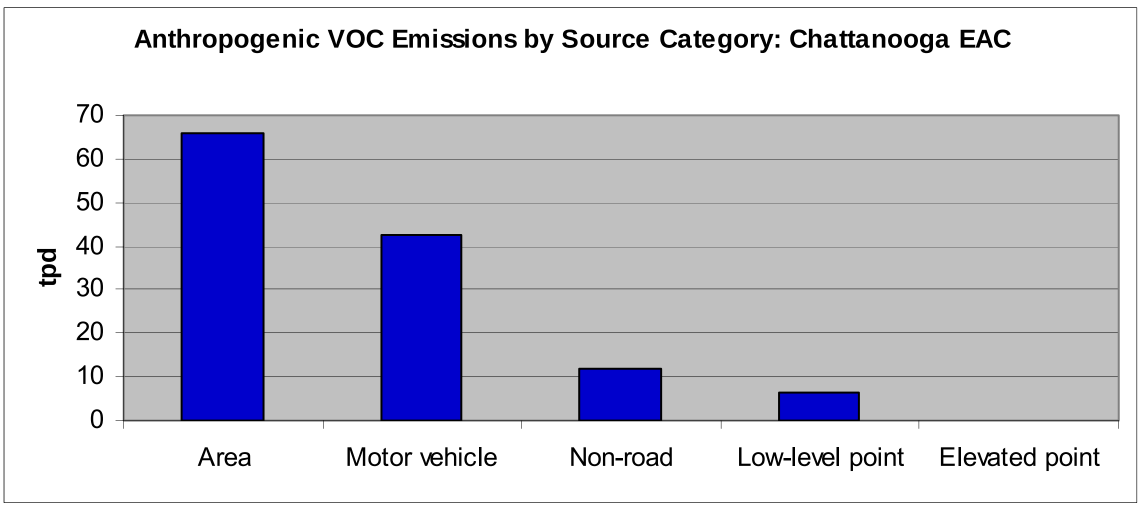
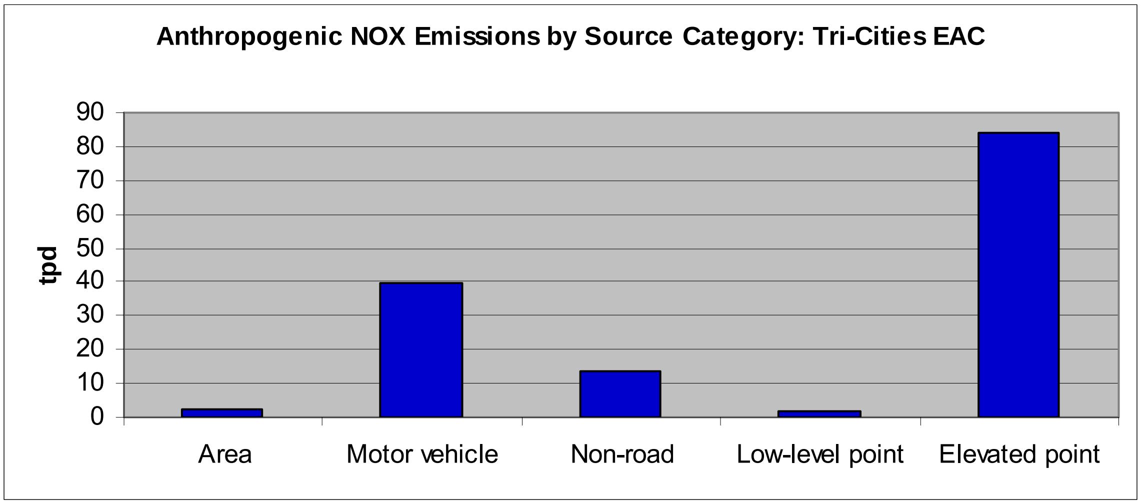
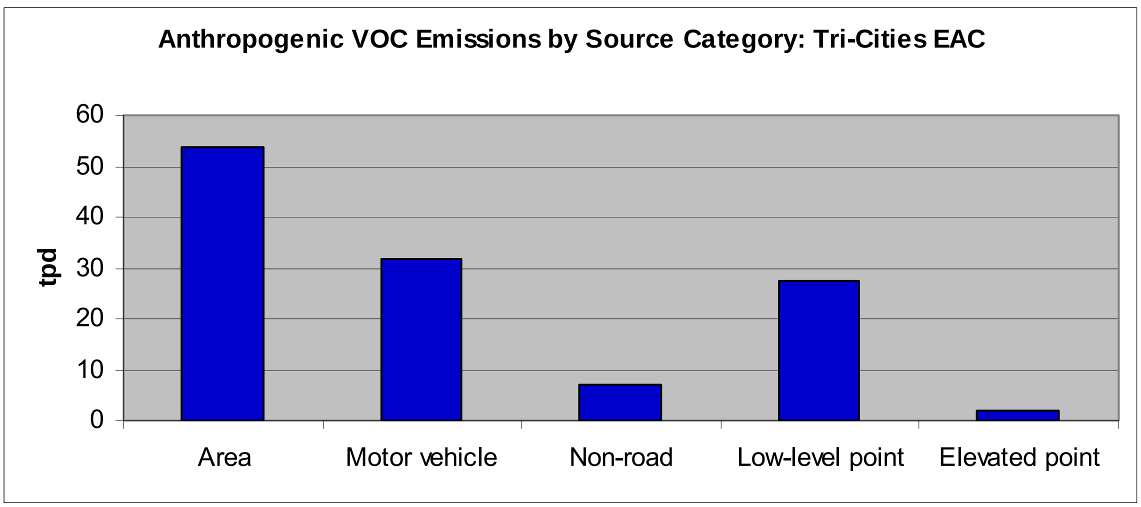


Figure 1-13e.
Weekday Anthropogenic Emissions (tpd) in the Tri-Cities EAC Area by Species and Source Category





In addition to anthropogenic sources, the ATMOS region has a high percentage of VOC emissions from biogenic sources, which are emitted from the region's extensive hardwood and softwood forests, other natural vegetation and from various crops that are raised in the region. The biogenic emissions in the ATMOS region make up about 90 percent of the total VOC emissions on a typical summer day. The percentage of the total VOC emissions from biogenic sources on a typical summer day is somewhat less for the EAC areas and is 71% for the Memphis area, 78% for the Nashville area, 79% for the Knoxville area (which includes portions of the GSM National Park), 86% for the Chattanooga area, and 79% for the Tri-Cities area.

There is some slight variation in emissions day to day during a typical summer, with some decreases in mobile emissions expected on weekend days and corresponding increases in non-road emissions, likely associated with the usage of recreational equipment. The anthropogenic and biogenic precursor emissions are affected by local and regional weather conditions, which affect the formation, transport, and deposition characteristics of ozone concentrations within the region.

Summary Conceptual Description of 8-Hour Ozone

In this section, we have begun to develop, through analysis of observed data and emission inventory information, a conceptual description of 8-hour ozone for the ATMOS region and the five EAC areas of interest.

Examination of 8-hour ozone data for the EAC areas for the 1996-2002 analysis period shows that

- All areas had some exceedance days, and the Memphis, Nashville, and Knoxville areas had 90^{th} percentile values greater than 84 ppb.
- The Knoxville area experienced the greatest number of exceedance days (nearly as many as Atlanta).
- July and August are the peak ozone months for most areas, although Nashville and the Tri-Cities areas had more exceedance in June than in July.
- The years 1997, 1998 and 1999 were high ozone years for most of the areas; in contrast, ozone concentrations tended to be lowest for 2001.
- Same-day correlations among the areas of interest suggest that 8-hour ozone concentrations are subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions.

Memphis

A more detailed analysis of the observed ozone data and meteorological conditions for the Memphis area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period. The Edmund Orgill Park site has the most number of exceedances and the DeSoto Co. site has the fewest. Currently the Marion site has the highest design value.
- The average diurnal profiles for ozone exceedance days vary among the sites. The Frayser site, an urban site, is characterized by a typical diurnal profile with a peak concentration during the midday hours. Later peaks at the other sites indicate some influence from ozone transport.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- There is no one upper-air wind pattern associated with exceedances in the Memphis area. When only high ozone days in the Memphis area are considered, there is a discernable shift to more northerly and easterly components during the time of the morning sounding. The percentage of time that the winds are from the north, northeast, south, and southeast is greater for ozone exceedance days than for all ozone season days.

Other meteorological factors also contribute to the incidence of high ozone in the Memphis area. Results from an application of the Classification and Regression Tree (CART) tool enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- Yesterday's maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high pressure to the east, high 850 mb temperatures, stable lapse rates, lower wind speed, and a tendency for southerly wind directions aloft (compared to lower ozone concentration days).

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Stability characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.

The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships.

Nashville

A more detailed analysis of the observed ozone data and meteorological conditions for the Nashville area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, but the most number of exceedances by far were recorded at the Rockland Rd. monitoring site. This site also has the highest design value for the Nashville EAC area.
- The average diurnal profiles for ozone exceedance days are generally characterized by a typical diurnal profile with a peak concentration during the midday hours.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- Similar to Memphis, the winds exhibit a range of wind directions on ozone exceedance days for Nashville, with a tendency for more southerly and easterly wind components on the exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Nashville area. Results from an application of CART enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- Yesterday's maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, clear skies, and lower wind speeds aloft.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Stability characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.
- Geopotential height tendency.

The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships. One of the exceedance bins is characterized by much lower temperatures and higher wind speeds and is representative of transitional period (spring or fall) high ozone days. Another of the bins is characterized by very high ozone on the prior day and otherwise very ozone conducive meteorological conditions. Days within this bin have the highest overall ozone concentrations.

Knoxville

A more detailed analysis of the observed ozone data and meteorological conditions for the Knoxville area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period. Several of the urban and GSM sites have more than 100 exceedance days and average annual maximum ozone concentrations greater than 100 ppb.
- The average diurnal profiles for ozone exceedance days are generally characterized by a typical diurnal profile with a peak concentration during the midday hours.
- Distinctly different diurnal profiles characterize sites located in the greater Knoxville area and in the GSM. The more urban sites show a mid-day peak. The elevated GSM sites show very flat diurnal profiles. The lack of variation throughout the day and specifically the lack of a distinct daytime peak indicate that ozone is transported into this area throughout the day (and not specifically formed during the daytime hours).

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- For exceedance days in the Knoxville area, the upper-level winds suggest a greater tendency for winds aloft to have a southerly component during high ozone days, especially at the time of the evening soundings. Westerly to southwesterly winds dominate the wind roses for the Knoxville area ozone exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Knoxville area. Results from an application of CART enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. The results indicate that:

- High ozone in the Knoxville area is associated with the regional day-to-day build up of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, high pressure to the west, and lower wind speeds and southerly wind directions aloft.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Stability and vertical mixing characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.
- Upper-level pressure/height patterns.

Three of the key exceedance bins share many similar characteristic and differ primarily with regard to wind and vertical mixing parameters. As for Nashville, one of the exceedance bins is characterized by much lower temperatures and higher wind speeds and is representative of transitional period (spring or fall) high ozone days. Another of the bins is characterized by very high ozone on the prior day and otherwise very ozone conducive meteorological conditions. Days within this bin have the highest overall ozone concentrations.

Chattanooga

A more detailed analysis of the observed ozone data and meteorological conditions for the Chattanooga area provided some key findings.

Analysis of the available ozone data reveals that:

- Both long-term sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, and experience high ozone about equally.
- The average diurnal profiles for ozone exceedance days are characterized by a typical diurnal profile with a peak concentration during the midday hours.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- Westerly to southerly winds are most common for exceedances days in the Chattanooga. Compared to the full ozone season, there is a greater tendency for winds from the south on ozone exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Chattanooga area. Results from an application of the Classification and Regression Tree (CART) tool enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- High ozone in the Chattanooga area is associated with relatively high ozone on the prior day—throughout the region. Thus, day-to-day build up or carryover of ozone is indicated for high ozone days.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Southerly surface wind directions are associated with the higher ozone categories.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures and stable lapse rates. Compared to all ozone season days, lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Surface and upper-air wind direction.
- Geopotential height/pressure patterns.

The combined differences in wind direction and regional ozone concentrations on the prior day, especially for the Atlanta area, provide variations on the transport component of 8-hour ozone for the exceedance bins.

Tri-Cities

A more detailed analysis of the observed ozone data for the Tri-Cities area provided some key findings.

Analysis of the available ozone data reveals that:

- Both long-term sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, and the Kingsport site tends to slightly higher ozone.
- The average diurnal profiles for ozone exceedance days are characterized by a typical diurnal profile with a peak concentration during the midday hours.

A detailed analysis of the meteorological conditions associated with high ozone in the Tri-Cities area was not performed, but it is expected, especially given the similarities between the results for Nashville and Knoxville and the geographical similarities to Knoxville, that the meteorological conditions associated with ozone exceedances in the Tri-Cities area are similar to those for Knoxville.

Episode Selection/Simulation Periods

Episode selection for the ATMOS EAC modeling/analysis was based on a review of historical meteorological and air quality data with emphasis on representing typical ozone exceedance events in the areas of interest. The episode selection was conducted in stages. First, in 2000, a primary multi-day simulation period was selected for the ATMOS modeling. This period was selected to optimize the representation of typical 8-hour ozone exceedance conditions and concentration levels for all of the areas of interest (which, for ATMOS, included all of the EAC areas with the exception of the Tri-Cities EAC area). A second multi-day simulation period was added in 2003, to enhance the robustness of the EAC modeling by including additional days and types of exceedance conditions. This episode was specifically selected to complement the first ATMOS simulation period in terms of representing different key meteorological conditions and providing additional exceedance days for certain areas. Finally, a third multi-day simulation period was added in 2004, as modeling databases from the State of Arkansas became available for use in the ATMOS study. This third simulation period includes additional exceedance days for all of the areas of interest and some variation on the exceedance meteorological conditions for certain of the areas. It provides important additional exceedance days for the Tri-Cities area.

Overall, the primary objective of the episode selection was to identify and assemble suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the ATMOS EAC areas of interest. Important considerations in selecting (and adding to) the episodes include (1) representing the range of meteorological conditions that accompany ozone exceedances, (2) representing the ozone concentration levels that characterize the nonattainment problem (and result in the designation of nonattainment), and (3) accounting for the frequency of occurrence of the exceedance meteorological regimes (to avoid using results from infrequent or extreme events to guide the decision making process).

The approach to episode selection is consistent with current (draft) EPA guidance (EPA, 1999a) on episode selection for 8-hour ozone attainment demonstration modeling. In this guidance, EPA lists the following as the most important criteria for choosing episodes:

- Monitored ozone concentrations comparable to the severity as implied by the form of the NAAQS.
- Representation of a variety of meteorological conditions observed to correspond to monitored ozone concentrations of the severity implied by the form of the NAAQS.
- Data availability.
- Selection of a sufficient number of days so that the modeled attainment test is based on several days.

EPA also provides several additional (secondary) criteria for episode selection:

- Episodes used in previous modeling exercises.
- Episodes drawn from the period on which the current design value is based.
- Observed concentrations are “close” to the design value for as many sites as possible.

- Episodes are appropriate for as many of the nonattainment areas as possible (when several areas are being modeled simultaneously).
- Episodes include weekend days.

Overview of the Methodology

The methodology used for selection of the first and second simulation periods was based on that developed for a similar study by Deuel and Douglas (1998) and used for the several other modeling studies including the Gulf Coast Ozone Study (GCOS) (Douglas et al. 2000). In selecting the first episode, days within the period 1990 to 1999 were considered. In selecting the second episode, days within the period 1996 to 2002 were considered. In both cases, the days were classified according to meteorological and air quality parameters using the Classification and Regression Tree (CART) analysis technique.

CART was applied separately for four of the five EAC areas: Memphis, Nashville, Knoxville, and Chattanooga. The results were reviewed with respect to classification accuracy and physical reasonableness. Once acceptable classification results were obtained, the information provided by CART was used to guide the episode selection.

For each area, the frequency of occurrence of ozone exceedances for each classification type was then determined. Only certain of the CART bins are associated with 8-hour ozone exceedances. To use the CART results to guide the episode selection analysis, we identified the exceedance bins with the most number of correctly classified days and designated these as key or primary bins. Specifically, we designated the CART bins with at least an average of one exceedance day per year for the analysis period as key exceedance bins.

An optimization procedure was applied to the selection of multi-day episodes for maximum achievement of the specified episode selection criteria (as outlined above) for as many areas as possible. Finally, a more detailed analysis of the episode days with respect to local meteorological conditions was conducted.

This integrated, multi-variate approach to episode selection ensures that the selected episodes represent the combined meteorological and air quality conditions associated with frequently occurring 8-hour ozone events.

The CART results also provide the basis for the development of an integrated “conceptual model” of 8-hour ozone. By examining the parameters associated with each classification category, and specifically the parameters and parameter values used to segregate the days into the various classification bins we can gain insight into the key differences between exceedance days and non-exceedance days, and the mechanisms contributing to high ozone events. We used this information on the relationships between air quality and meteorology to develop a conceptual model of 8-hour ozone for each area of interest, as presented in the previous section.

CART Application Procedures and Results

CART was applied for the period 1990-1999 and then, later in the course of the study, for the period 1996-2002. Here we present only the results from the more recent CART analysis in our discussion of the procedures and results. The procedures were identical for both analyses, the CART analysis results were comparable in both their content and accuracy, and, in both cases, the first (ATMOS) simulation period was easily identified as a very good candidate for regional scale modeling of the ATMOS region.

CART was applied separately for four of the five EAC areas: Memphis, Nashville, Knoxville, and Chattanooga. The classification (or dependent) variable for application of CART is daily maximum 8-hour average ozone concentration for the area of interest (the maximum of all sites within the area). This variable was assigned a value of 1 to 4, corresponding to a computed maximum 8-hour average ozone concentration of less than 65, 65 to less than 85, 85 to less than 105, or greater than or equal to 105 ppb. Thus, Categories 3 and 4 are the exceedance categories.

The ozone data were obtained from the U.S. EPA Aerometric Information and Retrieval System (AIRS). Note that sites with partial ozone records (relative to the analysis period) were not used in the CART analysis. This was done to avoid a changing basis for defining the maximum ozone concentration (and location), which could make it more difficult for CART to group/classify the days.

Surface and upper air meteorological data for sites representative of the regions of interest were obtained from the National Climatic Data Center (NCDC). Meteorological monitoring sites were assigned to each of the areas based on location and other geographical considerations. The sites are listed in Table 1-10.

In applying CART, it is necessary to construct a database of independent variables such that this relationship can be identified. The database that was used for each area consisted of only data for days for which a valid current-day daily maximum 8-hour ozone concentration for the area (this is the classification variable) was available. The air quality variables used in the CART are defined in Table 1-11. The surface meteorological variables used in the CART analysis are defined in Table 1-12, and the upper-air meteorological variables used the analysis are defined in Table 1-13.

Table 1-10.
Meteorological Monitoring Sites Used for CART for Each Area

CART Analysis Area	Surface Met Monitoring Site	Primary Upper-Air Met Monitoring Site
Memphis	Memphis	Little Rock
Nashville	Nashville	Nashville
Knoxville	Knoxville	Nashville
Chattanooga	Chattanooga	Nashville

Table 1-11.
Air Quality Variables Included in the CART Analysis

Variable Name	Description
(area)_8	*The classification variable*: a value of 1, 2, 3, or 4 depending on whether the maximum 8-hour ozone concentration over all sites in the urban area was <65, [65,85), [85,105), or ≥ 105 ppb.
ymx8o3_(area)	Yesterday's maximum 8-hour average ozone concentration in a given area.

Table 1-12.
Surface Meteorological Variables Included in the CART Analysis

Variable names are generic and vary slightly for each monitoring site.

Variable Name	Description
pmax	Maximum sea level pressure on the present day.
rh12	Surface relative humidity at noon.
tmax	Maximum surface temperature (ºC) for the present day.
wb710	Average surface wind direction bin from 0700 to 1000 LST (1=N, 2=E, 3=S, 4=W, 5=Calm[2]).
wb1013	Average surface wind direction bin from 1000 to 1300 LST.
wb1316	Average surface wind direction bin from 1300 to 1600 LST.
ws710	Average surface wind speed ms^{-1} from 0700 to 1000 LST.
ws1013	Average surface wind speed ms^{-1} from 1000 to 1300 LST.
ws1316	Average surface wind speed ms^{-1} from 1300 to 1600 LST.

Table 1-13.
Upper-Air Meteorological Variables Included in the CART Analysis

Variable names are generic and vary slightly for each monitoring site.

Variable Name	Description
wb85am	Wind direction bin value of 1 through 5, indicating that the wind direction corresponding to the morning sounding was from (in degrees) [315, 45), [45, 135),[135, 225), [225, 315), or calm[4] respectively.
wb85pm	Identical to above, but for the afternoons sounding.
ywb85pm	Identical to above, but for the previous afternoon's sounding.
ws85am	Upper-air 850 mb wind speed corresponding to the morning sounding.
ws85pm	Upper-air 850 mb wind speed corresponding to the afternoon sounding.
yws85pm	Upper-air 850 mb wind speed corresponding to the previous afternoon's sounding.
t85am	Upper-air 850 mb temperature corresponding to the morning sounding on the current day.
t85pm	Upper-air 850 mb temperature corresponding to the afternoon sounding on the current day.
y85pm	Upper-air 850 mb temperature corresponding to the afternoon sounding on the previous day.
rh85am	Upper-air 850 mb relative humidity corresponding to the morning sounding on the current day.
rh85pm	Upper-air 850 mb relative humidity corresponding to the afternoon sounding on the current day.
htthty	Difference between today's value and the value yesterday of the average of the morning and afternoon sounding heights above sea level of the 850 mb surface.
ht(s1)_(s2)85	The difference between the average of the morning and afternoon sounding heights about the level of the 850 mb surface at site #1 and site #2.
delt900	Difference between the temperature at 900 mb and the surface using the morning temperature sounding data.

[2] Calm winds are reported as a wind speed of zero.

Classification accuracy is summarized in Tables 1-14a through d, for each of the four areas. For Memphis, 78 percent of the days are correctly classified, and 73 percent of the exceedance days are correctly classified in exceedance bins. For Nashville, 79 percent of the days are correctly classified, and 82 percent of the exceedance days are correctly classified in exceedance bins. For Knoxville, these same values are 73 and 78 percent for all days and exceedance days, respectively. For Chattanooga, classification accuracy is 83 percent for all days and 80 percent for exceedance days. Most days that are misclassified are placed into a bin of a neighboring category. In several cases, the exceedance bins contain days that did not report observed exceedances. One possible reason for this is that while the meteorological conditions may have been conducive to ozone, high ozone may not have been measured at one of the monitoring sites. Our goal in applying CART (based on prior applications) was 80 percent accuracy for both all days and exceedance days. This was met or nearly met for all four areas.

Table 1-14a.
Summary of Classification Accuracy for the Memphis CART Analysis

		True Class			
		1	2	3	4
C	1	596	68	2	0
A	2	131	299	38	0
R	3	3	25	86	0
T	4	0	2	5	16

Table 1–14b.
Summary of Classification Accuracy for Nashville CART Analysis

		True Class			
		1	2	3	4
C	1	597	102	1	0
A	2	70	289	28	0
R	3	6	50	108	0
T	4	0	5	10	15

Table 1–14c.
Summary of Classification Accuracy for the Knoxville CART Analysis

		True Class			
		1	2	3	4
C	1	311	92	2	0
A	2	106	428	58	0
R	3	3	63	152	1
T	4	1	6	19	39

Table 1–14d.
Summary of Classification Accuracy for the Chattanooga CART Analysis

		True Class			
		1	2	3	4
C	1	716	72	1	0
A	2	80	265	18	0
R	3	4	24	59	0
T	4	2	5	4	12

An important step in the use of the CART results for episode selection is the identification of key exceedance bins. Key bins were chosen for each ATMOS area based on frequency of occurrence, with a minimal requirement of at least seven exceedance days in the bin, equivalent to one day per year for the analysis period. The key bins are used to guide the episode selection, such that days are preferentially selected from the more populated exceedance bins and as many key bins as possible are represented. This ensures that the most frequently occurring conditions as well as the range of conditions associated with ozone exceedances are represented. The number of key bins for each area is as follows: Memphis – 3, Nashville – 5, Knoxville – 5, Chattanooga – 3. The average parameter values and the conditions associated with each key bin are discussed in the previous section on the conceptual description.

Episode Selection Procedures and Results

The episode selection algorithm requires that the candidate modeling episode days be grouped according to ozone concentration level, and further grouped according to meteorological characteristics. For this analysis, we used the CART analysis technique to classify and group the days according to ozone concentration and meteorological conditions. As described above, all days included in the analysis are placed in classification bins – each corresponding to a specific ozone concentration range and a particular set of meteorological parameters. For each area, some number of these bins corresponds to exceedance level 8-hour ozone concentrations.

The next step in episode selection procedure is to select days that are representative of the key meteorological regimes (i.e., regimes frequently associated with ozone exceedances, based on the number of days in the CART classification bins). Other criteria may also be applied to the selection of days (e.g., in this case we optimized the possibility that the maximum ozone concentrations for the days selected to represent an area are within 10 ppb of the design value for that area, or, alternatively, to maximize the number of sites for which the site-specific maximum ozone concentration is within 10 ppb of the site-specific design value). These criteria are optimized across the areas of interest.

The episode selection algorithm makes use of a numerical procedure called simulated annealing to find an optimal set of days to satisfy a set of episode selection criteria. In applying this technique, an initial set of days is chosen from a user-provided input list that consists of days from those CART bins that represent key meteorological/ozone exceedance regimes. Then individual days from this set are randomly changed. After each substitution, a "cost" function, which determines how well the episode selection criteria are met, is evaluated. The formulation of the cost function is described in detail by Deuel and Douglas (1998). If the cost with the new day is less than the cost with the previous day, the substitution is retained. If the cost with the new day is higher than the cost with the previous day, there is still some small probabilistic chance that the change will be retained. This allows the cost function to escape from a local minimum, until it settles into a minimum close to the global value. The chance of increasing the cost through substitution of new days, however, diminishes as the algorithm progresses.

The user must specify a cost function that determines the set of days. In this analysis, the cost function was designed to (1) minimize the differences between the daily maximum ozone concentration for the selected days and the design value for each area included in the analysis and (2) form multi-day episodes (consisting of sequences of consecutive episode days). The relative importance of (1) and (2) was specified (4:1) to favor representation of the design value.

In applying the episode selection algorithm, we used only days from those bins that had seven or more exceedance days (one per year) during the analysis period (1996-2002). These are the key bins or "regimes."

In identifying the candidate episodes for modeling, we used the 2000-2002 design values for each area as a reference point[3]. The design-value-based criterion gave preference to days for which the maximum ozone concentration was within 10 ppb of the design value (DV) for a given area. The number of sites with maximum 8-hour ozone concentrations within 10 ppb of the site-specific design value was also examined, but was not used as an objective criterion in applying the algorithm.

Each area was considered separately and as part of an integrated analysis, designed such that the selected episode days are representative of not just one, but several or all of the areas of interest.

This approach was used to identify the first and second ATMOS episode periods. In selecting the first episode period, emphasis was placed on meeting the meteorological and design-value representativeness criteria for as many of the areas of interest and as many simulation days as possible. The 29 August–9 September 1999 simulation period was selected. In selecting the second episode period, emphasis was placed on complementing the August/September 1999

3 Note that for the first episode, the 1997-1999 design values were used and that these were generally higher than the 2000-2002 values, especially for Nashville. This results in the August/September episode being somewhat more severe than the other episodes.

simulation period such that the combined episode days improved the extent to which the criteria were met. We also reviewed ozone concentrations for candidate episode days for the Tri-Cities area, which was not considered in the full episode selection analysis and gave weight to those episodes with exceedances in this area. The 16-22 June 2001 simulation period was selected. The 4-10 July 2002 was a candidate episode for the ATMOS modeling analysis but satisfied fewer of the criteria than the June 2001 episode. However, this episode was added to the ATMOS modeling analysis, following the development of databases by ADEQ.

Characteristics of the episodes are summarized for each area in Table 1-15 below.

Table 1-15a.
Summary of ATMOS EAC Modeling Episodes Periods for Memphis.

The 2000-2002 8-hour ozone design value (DV) is 94 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Memphis 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	79.6	1	29
1999	8	30	71.7	0	29
1999	8	31	**96**	4	**17**
1999	9	1	**87.6**	1	**25**
1999	9	2	**95**	2	**17**
1999	9	3	**97.9**	3	9
1999	9	4	**106.8**	1	20
1999	9	5	64.9	0	33
1999	9	6	80.8	1	29
1999	9	7	**86.6**	3	11
1999	9	8	55.3	0	33
1999	9	9	49.3	0	7
2001	6	16	76.5	1	1
2001	6	17	77.6	0	**29**
2001	6	18	**91.4**	2	**29**
2001	6	19	83	2	**31**
2001	6	20	**93.9**	3	**17**
2001	6	21	57.8	0	33
2001	6	22	67.6	0	6
2002	7	4	78	0	**17**
2002	7	5	83.9	0	**29**
2002	7	6	78.5	0	18
2002	7	7	82.8	2	29
2002	7	8	**100**	3	21
2002	7	9	**88.1**	2	21
2002	7	10	77.5	1	29

Table 1–15b.
Summary of ATMOS EAC Modeling Episodes Periods for Nashville

The 2000-2002 8-hour ozone design value (DV) is 88 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Nashville 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	79.9	2	35
1999	8	30	70.3	0	35
1999	8	31	**92.1**	6	**7**
1999	9	1	**100.4**	3	31
1999	9	2	**103.1**	5	29
1999	9	3	**103.1**	6	25
1999	9	4	**110.1**	3	**26**
1999	9	5	**109.6**	1	**26**
1999	9	6	**96.8**	5	28
1999	9	7	80.5	4	**26**
1999	9	8	**90.3**	5	28
1999	9	9	60.1	0	35
2001	6	16	60.3	0	1
2001	6	17	78.3	2	**7**
2001	6	18	72.9	1	27
2001	6	19	**90**	6	**7**
2001	6	20	**103.3**	5	**18**
2001	6	21	58.7	0	36
2001	6	22	54.8	0	12
2002	7	4	81.4	2	13
2002	7	5	81.1	1	32
2002	7	6	**85.9**	4	**35**
2002	7	7	**92.6**	5	**34**
2002	7	8	83.2	1	**35**
2002	7	9	64.4	0	33
2002	7	10	67	0	9

Table 1–15c.
Summary of ATMOS EAC Modeling Episodes Periods for Knoxville

The 2000-2002 8-hour ozone design value (DV) is 98 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Knoxville 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	84.5	1	30
1999	8	30	82.5	1	30
1999	8	31	**88.5**	2	**23**
1999	9	1	**97.6**	2	20
1999	9	2	**104.1**	4	**23**
1999	9	3	**98.6**	4	25
1999	9	4	**101.6**	7	**23**
1999	9	5	83.6	0	**29**
1999	9	6	**86.9**	0	20
1999	9	7	**102.3**	2	**23**
1999	9	8	**95.1**	6	**27**
1999	9	9	**86.3**	0	14
2001	6	16	68	0	3
2001	6	17	81.3	1	**11**
2001	6	18	**95.3**	6	**23**
2001	6	19	**100.7**	7	**16**
2001	6	20	**103**	8	**26**
2001	6	21	**96.8**	7	**29**
2001	6	22	60.8	0	14
2002	7	4	**86.5**	1	**23**
2002	7	5	81.1	0	**23**
2002	7	6	**94.5**	4	**29**
2002	7	7	**95.8**	5	**23**
2002	7	8	**86.3**	0	20
2002	7	9	**93.8**	4	**29**
2002	7	10	71.1	0	30

Table 1–15d.
Summary of ATMOS EAC Modeling Episodes Periods for Chattanooga

The 2000-2002 8-hour ozone design value (DV) is 93 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Chattanooga 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	77.3	0	16
1999	8	30	70.6	0	12
1999	8	31	79.3	0	9
1999	9	1	**98.1**	2	**26**
1999	9	2	82.4	1	**26**
1999	9	3	**107**	1	**33**
1999	9	4	**98.3**	2	**26**
1999	9	5	**88.6**	2	**26**
1999	9	6	70	0	**26**
1999	9	7	**89.6**	1	15
1999	9	8	**93.3**	1	**26**
1999	9	9	62.1	0	28
2001	6	16	48.5	0	1
2001	6	17	74.5	0	9
2001	6	18	82.6	1	13
2001	6	19	**89.4**	2	**26**
2001	6	20	**99**	2	**26**
2001	6	21	72.5	0	27
2001	6	22	36.3	0	10
2002	7	4	63.4	0	10
2002	7	5	79.4	0	16
2002	7	6	**86.8**	2	**26**
2002	7	7	76.9	0	28
2002	7	8	**85**	1	20
2002	7	9	**91.4**	2	**26**
2002	7	10	69.9	0	9

Table 1–15e.
Summary of ATMOS EAC Modeling Episodes Periods for Tri-Cities

The 2000-2002 8-hour ozone design value (DV) is 92 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS are highlighted in bold.

Year	Month	Day	Tri-Cities 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	65.4	0	NA
1999	8	30	64	0	NA
1999	8	31	54.1	0	NA
1999	9	1	81.9	1	NA
1999	9	2	77.6	0	NA
1999	9	3	57.1	0	NA
1999	9	4	67.1	0	NA
1999	9	5	26.5	0	NA
1999	9	6	24.9	0	NA
1999	9	7	58.8	0	NA
1999	9	8	73.5	0	NA
1999	9	9	61.1	0	NA
2001	6	16	55	0	NA
2001	6	17	72.8	0	NA
2001	6	18	81.5	0	NA
2001	6	19	**101.8**	1	NA
2001	6	20	**87.1**	2	NA
2001	6	21	**87.9**	2	NA
2001	6	22	54.1	0	NA
2002	7	4	54.6	0	NA
2002	7	5	60.5	0	NA
2002	7	6	65.5	0	NA
2002	7	7	**91.9**	1	NA
2002	7	8	80.5	1	NA
2002	7	9	**92.6**	1	NA
2002	7	10	69.9	0	NA

Summary of Modeling Episodes

The three episodes selected for this study each include two start-up days and one clean out day. The length of each episode was designed to capture the entire high ozone cycle for each area of interest as influence by the synoptic and mesoscale meteorological conditions. The episodes also include both weekdays and weekend days. The three selected episodes include:

- 29 August–9 September 1999, Sunday–Thursday.
- 16–22 June 2001, Saturday–Friday.
- 4–10 July 2002, Thursday–Wednesday.

Area-specific observations are summarized below.

Memphis

The three modeling episodes include 10 exceedance days and represent two of the three key exceedance meteorological regimes as well as several other high ozone regimes for Memphis. The episodes also include:

- Nine exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Four additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 86 to 106 ppb.
- An average 8-hour ozone exceedance concentration of 94 ppb.

Nashville

The three modeling episodes include 12 exceedance days and represent four of the five key exceedance meteorological regimes for Nashville. The episodes also include:

- Six exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000–2002 design value (note that the 1999 episode was originally selected using the 1999 design value of 102 ppb—so many of the days are consistent with the design value during the 1997–1999 design value period, but not with the lower design value for 2000–2002).
- Four additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 85 to 110 ppb.
- An average 8-hour ozone exceedance concentration of 98 ppb.

Knoxville

The three modeling episodes include 18 exceedance days and represent four of the five key exceedance meteorological regimes as well as several other high ozone regimes for Knoxville. The episodes also include:

- Fourteen exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.

- Five additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 86 to 104 ppb.
- An average 8-hour ozone exceedance concentration of 95 ppb.

Chattanooga

The three modeling episodes include 11 exceedance days and represent two of the three key exceedance meteorological regimes for Chattanooga. The episodes also include:

- Ten exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Two additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 85 to 107 ppb.
- An average 8-hour ozone exceedance concentration of 93 ppb.

Tri-Cities

The three modeling episodes include five exceedance days for the Tri-Cities area. The episodes also include:

- Five exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Three additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 87 to 101 ppb.
- An average 8-hour ozone exceedance concentration of 92 ppb.

Report Contents

The remainder of this document summarizes the methods and results of the ATMOS EAC photochemical modeling analysis. Section 2 references the EAC modeling protocol, which is included as an appendix. Section 3 presents a summary of the base-case emissions inventory preparation. Section 4 presents the meteorological modeling and input preparation, and Section 5 summarizes the air quality, land-use, and chemistry inputs. Section 6 presents the model performance evaluation. Section 7 presents the future-year modeling analysis. Section 8 presents the modeled attainment demonstration and Section 9 presents an evaluation of maintenance for 2012. Section 10 provides a summary of review procedures followed in the analysis. Finally, Section 11 presents a summary of data access procedures.

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2. Modeling Protocol

The modeling protocol document for the ATMOS EAC 8-hour ozone attainment demonstration modeling analysis was prepared in May 2003. The protocol document provides information regarding the organizational structure of the modeling study, study participants, communication structures, and the resolution of technical difficulties. It also provides detailed information on each element of the modeling analysis including selection of the primary modeling tools, methods and results of the episode selection analysis, modeling domain, model input preparation procedures, model performance evaluation, use of diagnostic and sensitivity analysis, future-year modeling, application of the EPA ozone attainment demonstration procedures, and documentation procedures. Archival and data acquisition procedures are also outlined in this document. The modeling protocol document is provided in Appendix A and is also available as a separate document (SAI, 2003).

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3. Base-Case Modeling Emission Inventory Preparation

This section discusses the development of the base- and current-year emission inventories for the three ATMOS modeling episode periods. The general procedures followed and emission-processing tools used in preparing these inventories are summarized in the ATMOS EAC modeling protocol (SAI, 2003).

For ease of reading, all figures and tables follow the text of this section.

Emissions Data

The modeling inventories for the ATMOS 2001 base- and current-year episodes were prepared based on the following information:

- Final 1999 National Emission Inventory (NEI) Version 2.
- Emissions data provided by states or counties for specific years.
- Episode-day-specific emissions data provided by individual facilities.

The 1999 NEI inventory includes annual and ozone season daily (available for some of the source categories and states) emissions for oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter with a diameter less than 10 and 2.5 microns (PM_{10} and $PM_{2.5}$) and ammonia (NH_3).

Efforts were made to obtain the latest information available for each state in the modeling domain and to incorporate these data into the modeling inventory as permitted by the EAC schedule and resource limitations. The updates received are presented below.

Overview of Emissions Processing Procedures

To facilitate development of the detailed emission inventories required for photochemical modeling for this analysis, EPA's UAM Emission Preprocessor System, Version 2.5 (EPS 2.5) was used. This system, developed by SAI under the sponsorship of the EPA's Office of Air Quality Planning and Standards, consists of series of computer programs designed to perform the intensive data manipulation necessary to adapt a county-level annual or seasonal emission inventory for modeling use. EPS 2.5 provides the capabilities, and allows for the evaluation of proposed control measures for meeting Reasonable Further Progress (RFP) regulations and special study concerns.

The core EPS 2.5 system consists of a series of FORTRAN modules that incorporate spatial, temporal, and chemical resolution into an emission inventory used for photochemical modeling. Point, area, non-road and on-road mobile source emissions data were processed separately through the EPS 2.5 system to facilitate both data tracking for quality control and the use of data in evaluating the effects of alternative proposed control strategies on predicted future air pollutant concentrations.

Chemical Speciation

All point, area, non-road mobile, and on-road motor vehicle emissions were chemically speciated from VOC into the Carbon Bond Mechanism species corresponding to the toxics version of the mechanism (CB-IV-tox), then converted to the CB-V species corresponding to the latest version of the mechanism (SAI, 2002). The CB-IV speciation profiles were generated based on the toxic compounds database, and profile weights data file prepared for a previous study (Ligocki et al., 1992, Ligocki and Whitten, 1992). The VOC speciation profile assignments and VOC to THC conversion factors have been updated using the latest information provided by EPA (EPA, 2002a)

Temporal Allocation

The temporal variation profiles (monthly, weekly, and diurnal) assigned in the EPS 2.5 default input files for the area and non-road mobile source categories were included in the modeling inventory. The default temporal profiles and profile assignments to the source categories have been updated using the latest information provided by EPA (EPA, 2001). If peak ozone season emissions data were provided in the input inventory, no additional seasonal adjustments were applied.

For on-road motor vehicles, the default weekly and diurnal profiles provided with EPS 2.5 were used to allocate daily emission rates by hour.

The operating schedule (month/year, days/week and hours/day) information included in the point-source input data for each source was processed through EPS 2.5 utility to generate source-specific weekly and diurnal temporal variation profiles. These profiles were used to allocate the annual emissions to the daily emissions, adjust the daily emission rates for the day of the week, and to allocate the adjusted daily emissions to the hours of the episode day.

Episode-specific hourly emission rates (e.g., point-source data provided by Southern Company) were incorporated directly into the modeling inventory.

Spatial Allocation

Point-source emissions were directly assigned to grid cells based on the source location coordinates included in the input emissions data for each source.

County-level area and non-road mobile emissions were allocated to grid cells using a combination of gridded spatial allocation surrogates and link locations. The gridded spatial allocation surrogates file includes fractions by grid cell of county area, population, and land-use for each county. To prepare this file, SAI obtained gridded land-use data from the United States Geological Survey (USGS, 1990). The land-use database, which has a spatial resolution of approximately 200 by 200 meters, includes data for over 30 land-use categories. These categories were combined with the land-use categories required by EPS 2.5 (e.g., urban, rural, residential, agriculture, deciduous forest, coniferous forest, water and etc.). Population data from the Census Bureau for 2000 were gridded based on the location of the centroid of each census block and included in the spatial allocation surrogate file.

County-level on-road mobile emissions were allocated to grid cells using gridded roadway type and population. This file was prepared based on the Tiger/Line database (U.S. Census Bureau, 1993, 1994). The link data for limited access primary roads, primary roads without limited access, and secondary roads were extracted from the database, and used to generate the gridded roadway type surrogate file. The airport location data from the database was used to spatially allocate the emissions from aircraft.

The spatial distribution surrogate assignments for area source categories have been updated using the latest information provided by EPA (EPA, 2002b).

Preparation of the Area and Non-Road Emission Inventory Component

Area and non-road source emissions for all the states included in the ATMOS modeling domain were generated based on the 1999 NEI Ozone Season Daily estimates with the following exceptions:

- 2001 area source data provided by Davidson County, Tennessee.
- 2000 area and non-road source data for four counties in Little Rock area (Faulkner, Lonoke, Pulaski and Saline Counties) provided by ADEQ.
- 2000 area and non-road source data for State of Texas provided by the Texas Commission on Environmental Quality (TCEQ).

County-level emissions estimates for the majority of non-road source emissions were developed using EPA's Draft NONROAD2002a model (EPA, 2003) with the monthly maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state for the episode period. Aircraft, commercial marine and locomotives were not included in the NONROAD model, and the emissions for the categories were taken from the 1999 NEI Version 2 data.

Modifications were made to the 1999 NEI data to correct identified errors or make some improvements to the database. The details are as follows:

- The emissions from commercial marine vessels in the Pensacola area (Escambia, Santa Rosa, Okaloosa and Walton counties in State of Florida; and Baldwin and Mobile counties in State of Alabama) were estimated based on the Peninsular Florida Ozone Study (Alpine Geophysics, 2003), and the emissions were spatially allocated to the shipping lanes.
- Used the NET 96 version 3 emission estimates for aircraft for Escambia and Santa Rosa counties, Florida (there are no aircraft emissions data for Santa Rosa County, and very low values for aircraft emissions for Escambia County in NEI99 Version 2 data base).
- Used the emission estimates for railroad for Pickens and Tuscaloosa counties, Alabama provided by ADEM.
- Used the emission estimates for commercial marine vessels for East Baton Rouge and Iberville Parishes, Louisiana provided in 1997/1999 LDEQ data

Preparation of the Mobile-Source Emission Inventory Component

The county-level emission estimates for the on-road mobile source emissions were developed using MOBILE6.

For States of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee and Texas, state provided county-level daily VMT data, and 30-year historical average temperatures and humidity data for each month of the episode periods were used for the MOBILE6 runs. The details of state VMT data are as follows:

- States of Alabama (2000) and Arkansas (2000): VMT data prorated to 2001 using formulas provided by the states.
- States of Florida, Georgia, Mississippi, South Carolina, North Carolina, Tennessee and Texas: 2001 VMT data.
- State of Louisiana: 2000 VMT data.

For the other states within the modeling domain, the 2000 state-level VMT data provided by the Federal Highway Administration (FHWA) along with seasonal average temperatures were used for the MOBILE6 runs. The state-level VMT data were distributed to the county-level using the 2000 Census population as a surrogate.

The MOBILE6 input files were used to generate the emission factors for total organic gasses (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6 by the county-level VMT for that vehicle class and roadway classification using the program MVCALC.

Preparation of Point-Source Emission Inventory Component

The point source emissions were generated based on the following databases:

State of Tennessee

- 2001 point source data provided by Davidson County.
- 2000/2001 point source data provided by Knox County.
- 2001 point source data provided by Hamilton County (NEI99 Version 2 data with 1999 to 2001 facility closures).
- 2002 point source data provided by Shelby County.
- 1999 point source data for rest of 91 counties provided by University of Tennessee.
- 2001 point source data provided by Eastman Chemical Company located in Sullivan County, Tennessee.
- Gas compressor facility data provided by the various facilities, including actual emissions for large gas compressor stations for August/September 1999 and June 2001; actual 2001 emissions for small compressor stations; and revised stack parameters.

State of Mississippi

- 2001 point source data provided by MDEQ.

State of Texas

- 2000 point source data provided by TCEQ.

Facility-Specific Point Source Data

- Hourly day-specific data for June 2001 episode provided by Southern Company, which were also used for the current year inventories of the September 1999 and July 2002 episodes using day of week matches.
- Hourly day-specific data for June 2001 episode provided by TVA, which were also used for the current year inventories for the September 1999 and July 2002 episodes using day of week matches..
- Hourly day-specific data for June 2001 episode for three Entergy facilities (Independence, White Bluff and R S Nelson) provided by Entergy, which were also used for the current year inventories for the September 1999 and July 2002 episodes using day of week matches..

Other States

- 1999 NEI Version 2 point source data for other states.

The temporal profiles were applied to the annual emissions for each episode period.

The episode-specific point source data included hourly emission rates, and the information was used to calculate daily emissions, and create the episode-specific diurnal profiles for each source for each episode day. In addition to the location, stack height, and exit diameter, the point source data provided by Southern Company included hourly flow rate and exit temperature for each source, and this information was incorporated in the modeling inventory.

Estimation of Biogenic Emissions

The EPA's Biogenic Emission Inventory System (BEIS-2) was used to estimate day-specific biogenic emissions for the modeling analysis with the Version 3.1 of the Biogenic Emissions Landcover Database (BELD3). Gridded surrogates of land use/vegetation information were created at 4-km resolution for the entire modeling domain based on the 1-km BELD3 data. Biogenic emissions were then calculated using the 4-km resolution information. The use of BEIS-2 with the new high-resolution land use database is referred to as BEIS-2+. Temperature and solar radiation estimates were extracted from the output of the MM5 meteorological model.

Quality Assurance

Two levels of quality assurance were performed in preparing the emissions inventory. The first regards the inherent quality of the data input to EPS 2.5. The base year inventory database used to develop the UAM-V modeling inventories, along with the available documentation were reviewed. The review consist of an overall assessment of the inventory to ensure that the minimum data requirements and quality standards set forth in *Emission Inventory Requirements for Ozone State Implementation Plans* (EPA-450/4-91-010, March 1991) are met. For example, emissions summaries were made for area and point sources from NEI 99 Version 2 database for the ATMOS states, compared with emissions from NET 96 Version 3 database and available state-specific data. It was concluded that point source data provided by MDEQ include more complete information for stack parameters, and the MDEQ point source data were used for State of Mississippi instead of NEI 99 Version 2 database.

The second phase of this effort involved verifying that all required processing steps were completed in an appropriate order. For the future-year modeling inventory, the review focused on the control assumptions and projection factors used to estimate future-year emission rates. The summary message files produced by each EPS 2.5 module were reviewed to identify any warning or error messages indicating potential problems in processing and to verify input and output emission totals for each processing step.

Graphic representations of the spatial variation in each component (e.g., area source emissions, biogenic emissions) of the final UAM-V ready modeling inventory files were prepared and reviewed for reasonableness.

After the inventory components were completed and merged, the emissions were summarized by major inventory component for all grids in the modeling domain for each of the episode days. The final review was performed before the UAM-V modeling.

Summary of the Modeling Emission Inventories

The emission summaries for the base- and current-year emissions for the two ATMOS episodes are presented in Table 3-1 through Table 3-6

- Table 3-1 through Table 3-3 for the base case August/September 1999 episode.
- Table 3-4 through Table 3-6 for the current-year June 2001 episode.
- Table 3-7 through Table 3-9 for the current-year July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are in tons per day.

Graphical depictions of the emissions are provided for Grid 3 in various figures that follow the tables. Biogenic VOC emission estimates derived using the BEIS-2+ algorithm differ by episode day due to different ambient temperatures. Figure 3-1 presents emission density plot of biogenic VOC emissions for one representative day for the June 2001 episode.

Anthropogenic emissions do not vary as much day-to-day as biogenic emissions. Figures 3-2a and 3-2b present NOx and VOC emission density plots for total low-level anthropogenic emissions, respectively, for 18 June 2001, illustrating emissions for a typical weekday for the episode. Figures 3-3a and 3-3b present NO_x and VOC emissions, respectively, for elevated point sources for 18 June 2001 for ATMOS Grid 1. The locations of the circles depict the location of the sources while the size of the circles represents the magnitude of the emissions.

Table 3-1.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 1.

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	1927	2111	2111	2111	2111	2111	1989	1927	1927	2111	2111	2111
Motor vehicle	8395	10094	10294	10194	10394	11094	9595	8395	8395	10294	10194	10394
Non-road	4627	5850	5850	5850	5850	5850	4627	4627	4627	5850	5850	5850
Low-level point	1717	1840	1840	1840	1840	1840	1760	1717	1717	1840	1840	1840
Biogenic	3411	3014	3040	3319	3475	3421	3406	3248	3239	3177	3016	2809
All low-level	20078	22910	23135	23314	23670	24316	21376	19914	19905	23272	23012	23004
Elevated point	13454	14628	14648	14632	14630	14542	14186	13454	13454	14648	14632	14630
Total Anthropogenic	30121	34524	34743	34628	34825	35437	32155	30121	30121	34743	34628	34825
TOTAL	33532	37538	37782	37946	38300	38858	35561	33369	33360	37920	37644	37635

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	12648	12652	12652	12652	12652	12652	12649	12648	12648	12652	12652	12652
Motor vehicle	5938	7140	7281	7211	7352	7847	6787	5938	5938	7281	7211	7352
Non-road	3758	2461	2461	2461	2461	2461	3758	3758	3758	2461	2461	2461
Low-level point	1897	2839	2839	2839	2839	2839	2081	1897	1897	2839	2839	2839
Biogenic	136177	93572	88106	97692	99489	96235	91448	84182	96556	92786	85907	72467
All low-level	160419	118665	113340	122855	124794	122034	116724	108424	120798	118020	111070	97771
Elevated point	514	611	611	611	610	609	544	514	514	611	611	610
Total Anthropogenic	24756	25704	25845	25775	25915	26409	25819	24756	24756	25845	25775	25915
TOTAL	160933	119276	113951	123466	125405	122644	117267	108938	121312	118632	111681	98382

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	10853	10904	10904	10904	10904	10904	10870	10853	10853	10904	10904	10904
Motor vehicle	57871	69584	70961	70273	71650	76473	66139	57871	57871	70961	70273	71650
Non-road	31028	29499	29499	29499	29499	29499	31028	31028	31028	29499	29499	29499
Low-level point	3215	3508	3508	3508	3508	3508	3315	3215	3215	3508	3508	3508
All low-level	102968	113495	114873	114184	115562	120384	111352	102968	102968	114873	114184	115562
Elevated point	4392	4713	4712	4709	4706	4696	4614	4392	4392	4712	4709	4706
Total Anthropogenic	107360	118208	119585	118893	120268	125080	115966	107360	107360	119585	118893	120268
TOTAL	107360	118208	119585	118893	120268	125080	115966	107360	107360	119585	118893	120268

Table 3-2.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 2

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	905	997	997	997	997	997	936	905	905	997	997	997
Motor vehicle	3581	4306	4391	4349	4434	4732	4093	3581	3581	4391	4349	4434
Non-road	1785	2236	2236	2236	2236	2236	1785	1785	1785	2236	2236	2236
Low-level point	626	670	670	670	670	670	640	626	626	670	670	670
Biogenic	1074	928	880	959	969	960	993	990	1002	952	900	858
All low-level	7971	9138	9175	9212	9307	9597	8447	7887	7899	9248	9153	9196
Elevated point	6048	6276	6280	6286	6290	6204	6182	6048	6048	6280	6286	6290
Total Anthropogenic	12945	14486	14576	14539	14628	14841	13636	12945	12945	14576	14539	14628
TOTAL	14018	15414	15455	15499	15597	15801	14629	13935	13947	15528	15440	15485

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	5292	5293	5293	5293	5293	5293	5292	5292	5292	5293	5293	5293
Motor vehicle	2328	2799	2854	2827	2882	3076	2660	2328	2328	2854	2827	2882
Non-road	1390	900	900	900	900	900	1390	1390	1390	900	900	900
Low-level point	800	1278	1278	1278	1278	1278	895	800	800	1278	1278	1278
Biogenic	84768	58404	52616	57869	57446	57926	63006	52505	61920	57271	52025	41736
All low-level	94577	68673	62941	68166	67799	68472	73243	62314	71729	67596	62323	52089
Elevated point	224	277	277	277	277	276	239	224	224	277	277	277
Total Anthropogenic	10034	10547	10602	10574	10630	10823	10477	10034	10034	10602	10574	10630
TOTAL	94801	68950	63218	68443	68076	68749	73482	62538	71953	67873	62600	52366

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	5668	5690	5690	5690	5690	5690	5675	5668	5668	5690	5690	5690
Motor vehicle	24192	29089	29665	29377	29953	31969	27649	24192	24192	29665	29377	29953
Non-road	10911	10584	10584	10584	10584	10584	10911	10911	10911	10584	10584	10584
Low-level point	1056	1112	1112	1112	1112	1112	1076	1056	1056	1112	1112	1112
All low-level	41827	46474	47050	46762	47338	49354	45310	41827	41827	47050	46762	47338
Elevated point	1614	1692	1689	1686	1684	1678	1642	1614	1614	1689	1686	1684
Total Anthropogenic	43442	48166	48740	48448	49022	51032	46953	43442	43442	48740	48448	49022
TOTAL	43442	48166	48740	48448	49022	51032	46953	43442	43442	48740	48448	49022

Table 3-3.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 3.

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	269	293	293	293	293	293	277	269	269	293	293	293
Motor vehicle	1718	2066	2107	2087	2127	2271	1964	1718	1718	2107	2087	2127
Non-road	673	874	874	874	874	874	673	673	673	874	874	874
Low-level point	126	139	139	139	139	139	130	126	126	139	139	139
Biogenic	378	336	314	353	377	375	362	363	358	346	327	306
All low-level	3163	3707	3727	3744	3810	3951	3406	3148	3143	3758	3719	3738
Elevated point	1783	1926	1936	1910	1920	1885	1860	1783	1783	1936	1910	1920
Total Anthropogenic	4568	5297	5349	5302	5353	5461	4903	4568	4568	5349	5302	5353
TOTAL	4946	5633	5663	5655	5730	5836	5266	4931	4926	5694	5629	5658

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	2252	2253	2253	2253	2253	2253	2253	2252	2252	2253	2253	2253
Motor vehicle	1042	1253	1278	1266	1291	1377	1191	1042	1042	1278	1266	1291
Non-road	640	412	412	412	412	412	640	640	640	412	412	412
Low-level point	314	498	498	498	498	498	359	314	314	498	498	498
Biogenic	33636	25595	21501	26083	28484	28505	29671	24904	25682	25391	24251	16207
All low-level	37884	30012	25943	30513	32938	33046	34113	29153	29931	29833	28680	20661
Elevated point	118	145	145	145	145	145	121	118	118	145	145	145
Total Anthropogenic	4366	4562	4587	4574	4599	4686	4564	4366	4366	4587	4574	4599
TOTAL	38002	30157	26088	30657	33083	33191	34234	29270	30048	29978	28825	20806

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	2302	2309	2309	2309	2309	2309	2304	2302	2302	2309	2309	2309
Motor vehicle	11283	13566	13835	13701	13969	14909	12895	11283	11283	13835	13701	13969
Non-road	5030	4932	4932	4932	4932	4932	5030	5030	5030	4932	4932	4932
Low-level point	195	213	213	213	213	213	203	195	195	213	213	213
All low-level	18810	21021	21289	21155	21424	22364	20433	18810	18810	21289	21155	21424
Elevated point	795	854	854	853	854	852	803	795	795	854	853	854
Total Anthropogenic	19605	21875	22143	22008	22278	23216	21236	19605	19605	22143	22008	22278
TOTAL	19605	21875	22143	22008	22278	23216	21236	19605	19605	22143	22008	22278

Table 3-4.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 1.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	1989	1927	2111	2111	2111	2111	2111
Motor vehicle	9584	8386	10083	10282	10183	10382	11081
Non-road	5484	5484	7127	7127	7127	7127	7127
Low-level point	1790	1746	1860	1860	1860	1860	1860
Biogenic	3468	3466	3640	3313	2979	2964	2958
All low-level	22314	21009	24821	24694	24260	24444	25138
Elevated point	15228	14447	15738	15758	15743	15740	15652
Total Anthropogenic	34073	31989	36920	37139	37024	37221	37832
TOTAL	37542	35455	40560	40452	40003	40185	40790

VOC	010616	010617	010618	010619	010620	010621	010622
Area	12649	12648	12652	12652	12652	12652	12652
Motor vehicle	6839	5984	7195	7337	7266	7408	7907
Non-road	6897	6897	3591	3591	3591	3591	3591
Low-level point	2082	1900	2831	2831	2831	2831	2831
Biogenic	132346	140983	155781	121735	96098	83973	78561
All low-level	160813	168411	182050	148146	122438	110456	105542
Elevated point	548	518	607	607	607	606	605
Total Anthropogenic	29014	27945	26875	27018	26947	27088	27586
TOTAL	161360	168928	182657	148753	123045	111062	106147

CO	010616	010617	010618	010619	010620	010621	010622
Area	10870	10853	10904	10904	10904	10904	10904
Motor vehicle	66566	58245	70032	71419	70726	72113	76966
Non-road	48550	48550	40822	40822	40822	40822	40822
Low-level point	3338	3239	3552	3552	3552	3552	3552
All low-level	129324	120887	125310	126697	126004	127391	132244
Elevated point	4654	4434	4753	4752	4749	4746	4735
Total Anthropogenic	133978	125321	130064	131449	130752	132136	136980
TOTAL	133978	125321	130064	131449	130752	132136	136980

Table 3-5.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 2.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	936	905	997	997	997	997	997
Motor vehicle	4082	3571	4294	4379	4337	4422	4719
Non-road	2017	2017	2567	2567	2567	2567	2567
Low-level point	638	623	670	670	670	670	670
Biogenic	1009	1075	1116	1063	980	912	869
All low-level	8681	8192	9645	9677	9552	9569	9824
Elevated point	6667	6531	6759	6764	6770	6773	6688
Total Anthropogenic	14339	13647	15288	15378	15341	15430	15642
TOTAL	15348	14723	16404	16441	16321	16342	16511

VOC	010616	010617	010618	010619	010620	010621	010622
Area	5292	5292	5293	5293	5293	5293	5293
Motor vehicle	2702	2364	2843	2899	2871	2927	3124
Non-road	2412	2412	1233	1233	1233	1233	1233
Low-level point	898	803	1274	1274	1274	1274	1274
Biogenic	82542	93498	100850	76477	61065	50946	43749
All low-level	93846	104369	111493	87176	71736	61674	54674
Elevated point	241	226	271	271	271	271	270
Total Anthropogenic	11546	11097	10914	10970	10942	10998	11195
TOTAL	94088	104595	111764	87447	72007	61944	54944

CO	010616	010617	010618	010619	010620	010621	010622
Area	5675	5668	5690	5690	5690	5690	5690
Motor vehicle	27988	24490	29446	30029	29738	30321	32362
Non-road	15862	15862	13329	13329	13329	13329	13329
Low-level point	1078	1058	1118	1118	1118	1118	1118
All low-level	50604	47079	49583	50166	49875	50458	52499
Elevated point	1655	1627	1701	1698	1695	1693	1687
Total Anthropogenic	52259	48706	51284	51865	51569	52151	54186
TOTAL	52259	48706	51284	51865	51569	52151	54186

Table 3-6.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 3.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	277	269	293	293	293	293	293
Motor vehicle	1960	1715	2062	2103	2082	2123	2266
Non-road	747	747	974	974	974	974	974
Low-level point	132	129	142	142	142	142	142
Biogenic	350	389	400	391	374	336	307
All low-level	3465	3247	3871	3903	3865	3868	3983
Elevated point	1929	1852	1996	2006	1980	1990	1955
Total Anthropogenic	5045	4711	5467	5518	5471	5522	5630
TOTAL	5395	5099	5867	5909	5845	5858	5938

VOC	010616	010617	010618	010619	010620	010621	010622
Area	2253	2252	2253	2253	2253	2253	2253
Motor vehicle	1215	1063	1279	1304	1291	1317	1405
Non-road	1023	1023	530	530	530	530	530
Low-level point	364	319	503	503	503	503	503
Biogenic	32242	38969	39530	33605	31571	24887	16452
All low-level	37096	43626	44094	38195	36148	29489	21143
Elevated point	122	118	137	137	137	137	137
Total Anthropogenic	4976	4775	4701	4727	4714	4739	4828
TOTAL	37217	43744	44231	38331	36285	29626	21280

CO	010616	010617	010618	010619	010620	010621	010622
Area	2304	2302	2309	2309	2309	2309	2309
Motor vehicle	13089	11453	13770	14043	13907	14179	15134
Non-road	6651	6651	5729	5729	5729	5729	5729
Low-level point	200	191	211	211	211	211	211
All low-level	22243	20596	22020	22293	22156	22429	23383
Elevated point	802	794	848	848	847	848	846
Total Anthropogenic	23045	21390	22868	23140	23003	23277	24230
TOTAL	23045	21390	22868	23140	23003	23277	24230

Table 3-7.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 1.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	1927	2111	1989	1927	2111	2111	2111
Motor vehicle	8340	11021	9531	8340	10028	10226	10127
Non-road	5398	6995	5398	5398	6995	6995	6995
Low-level point	1746	1860	1790	1746	1860	1860	1860
Biogenic	4236	3944	3766	3962	4238	4206	3747
All low-level	21648	25931	22474	21373	25233	25399	24841
Elevated point	14447	15652	15228	14447	15738	15758	15743
Total Anthropogenic	31858	37640	33936	31858	36733	36951	36836
TOTAL	36094	41584	37702	35820	40971	41157	40583

VOC	010704	010705	010706	010707	010708	010709	010710
Area	12648	12652	12649	12648	12652	12652	12652
Motor vehicle	6044	7986	6907	6044	7267	7411	7339
Non-road	6725	3518	6725	6725	3518	3518	3518
Low-level point	1900	2831	2082	1900	2831	2831	2831
Biogenic	145738	141756	139354	149280	157141	141002	119165
All low-level	173055	168743	167718	176596	183408	167414	145504
Elevated point	518	605	548	518	607	607	607
Total Anthropogenic	27834	27592	28911	27834	26875	27019	26947
TOTAL	173573	169348	168266	177114	184015	168021	146111

CO	010704	010705	010706	010707	010708	010709	010710
Area	10853	10904	10870	10853	10904	10904	10904
Motor vehicle	58780	77674	67178	58780	70676	72076	71376
Non-road	47454	39912	47454	47454	39912	39912	39912
Low-level point	3239	3552	3338	3239	3552	3552	3552
All low-level	120326	132042	128840	120326	125044	126444	125744
Elevated point	4434	4735	4654	4434	4753	4752	4749
Total Anthropogenic	124760	136777	133494	124760	129797	131196	130492
TOTAL	124760	136777	133494	124760	129797	131196	130492

Table 3-8.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 2.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	905	997	936	905	997	997	997
Motor vehicle	3535	4672	4041	3535	4251	4335	4293
Non-road	1987	2521	1987	1987	2521	2521	2521
Low-level point	623	670	638	623	670	670	670
Biogenic	1203	1179	1137	1124	1166	1198	1145
All low-level	8254	10040	8738	8175	9606	9722	9627
Elevated point	6531	6688	6667	6531	6759	6764	6770
Total Anthropogenic	13582	15548	14268	13582	15199	15287	15252
TOTAL	14784	16727	15405	14706	16365	16486	16396

VOC	010704	010705	010706	010707	010708	010709	010710
Area	5292	5293	5292	5292	5293	5293	5293
Motor vehicle	2407	3181	2751	2407	2894	2951	2923
Non-road	2352	1209	2352	2352	1209	1209	1209
Low-level point	803	1274	898	803	1274	1274	1274
Biogenic	87514	90505	90960	92573	96242	92838	76053
All low-level	98367	101463	102253	103427	106912	103566	86752
Elevated point	226	270	241	226	271	271	271
Total Anthropogenic	11080	11227	11534	11080	10942	10999	10970
TOTAL	98594	101733	102495	103653	107183	103836	87023

CO	010704	010705	010706	010707	010708	010709	010710
Area	5668	5690	5675	5668	5690	5690	5690
Motor vehicle	24860	32850	28411	24860	29891	30483	30187
Non-road	15502	13037	15502	15502	13037	13037	13037
Low-level point	1058	1118	1078	1058	1118	1118	1118
All low-level	47088	52695	50667	47088	49736	50328	50032
Elevated point	1627	1687	1655	1627	1701	1698	1695
Total Anthropogenic	48716	54383	52322	48716	51437	52026	51727
TOTAL	48716	54383	52322	48716	51437	52026	51727

Table 3-9.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 3.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	269	293	277	269	293	293	293
Motor vehicle	1690	2233	1931	1690	2032	2072	2052
Non-road	735	955	735	735	955	955	955
Low-level point	129	142	132	129	142	142	142
Biogenic	426	444	438	410	423	438	438
All low-level	3247	4067	3513	3232	3845	3900	3880
Elevated point	1852	1955	1929	1852	1996	2006	1980
Total Anthropogenic	4674	5578	5004	4674	5418	5468	5422
TOTAL	5099	6022	5442	5084	5841	5906	5860

VOC	010704	010705	010706	010707	010708	010709	010710
Area	2252	2253	2253	2252	2253	2253	2253
Motor vehicle	1088	1438	1243	1088	1308	1334	1321
Non-road	997	519	997	997	519	519	519
Low-level point	319	503	364	319	503	503	503
Biogenic	32335	42509	45719	40079	41123	41730	38171
All low-level	36991	47222	50576	44735	45706	46339	42768
Elevated point	118	137	122	118	137	137	137
Total Anthropogenic	4775	4850	4979	4775	4720	4746	4733
TOTAL	37109	47359	50698	44854	45843	46476	42904

CO	010704	010705	010706	010707	010708	010709	010710
Area	2302	2309	2304	2302	2309	2309	2309
Motor vehicle	11674	15427	13342	11674	14037	14315	14176
Non-road	6502	5605	6502	6502	5605	5605	5605
Low-level point	191	211	200	191	211	211	211
All low-level	20669	23552	22348	20669	22162	22440	22301
Elevated point	794	846	802	794	848	848	847
Total Anthropogenic	21463	24398	23150	21463	23010	23288	23148
TOTAL	21463	24398	23150	21463	23010	23288	23148

Figure 3-1.
Biogenic VOC Emissions in Grid 3

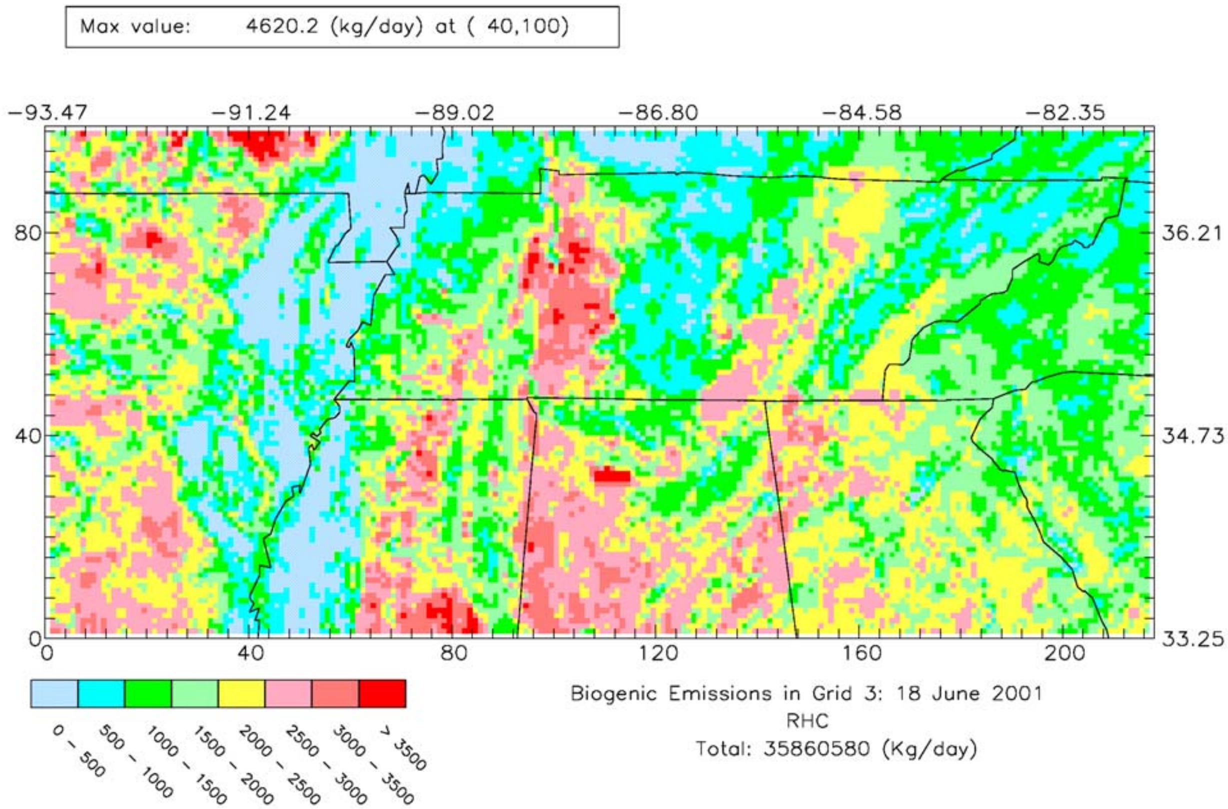


Figure 3-2a
Low-level Anthropogenic NO_x Emissions in Grid 3

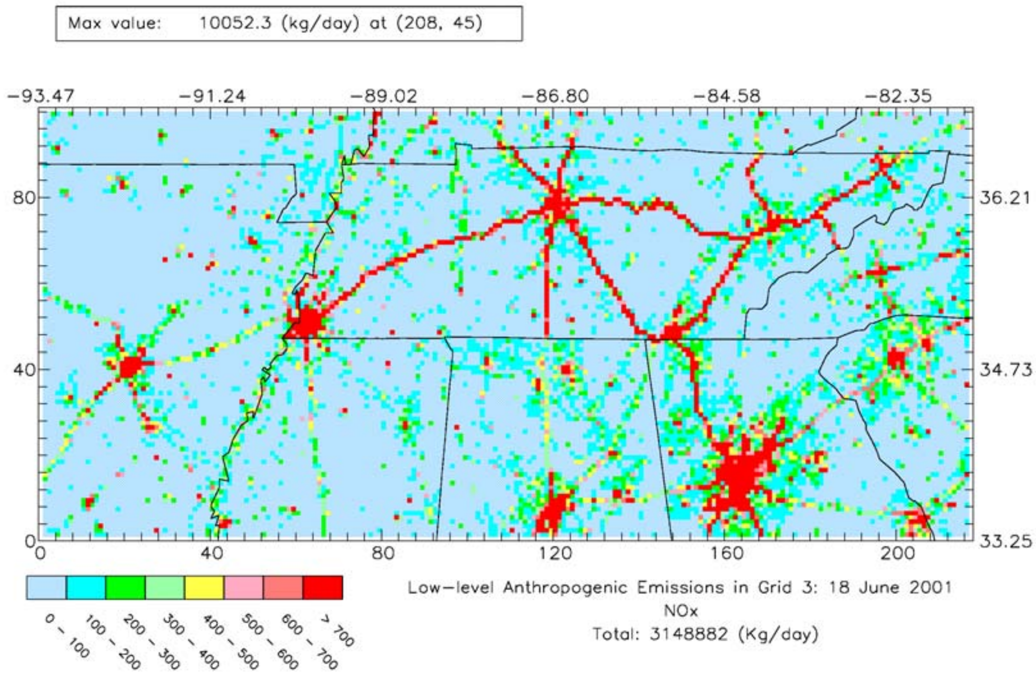


Figure 3-2b
Low-level Anthropogenic VOC Emissions in Grid 3

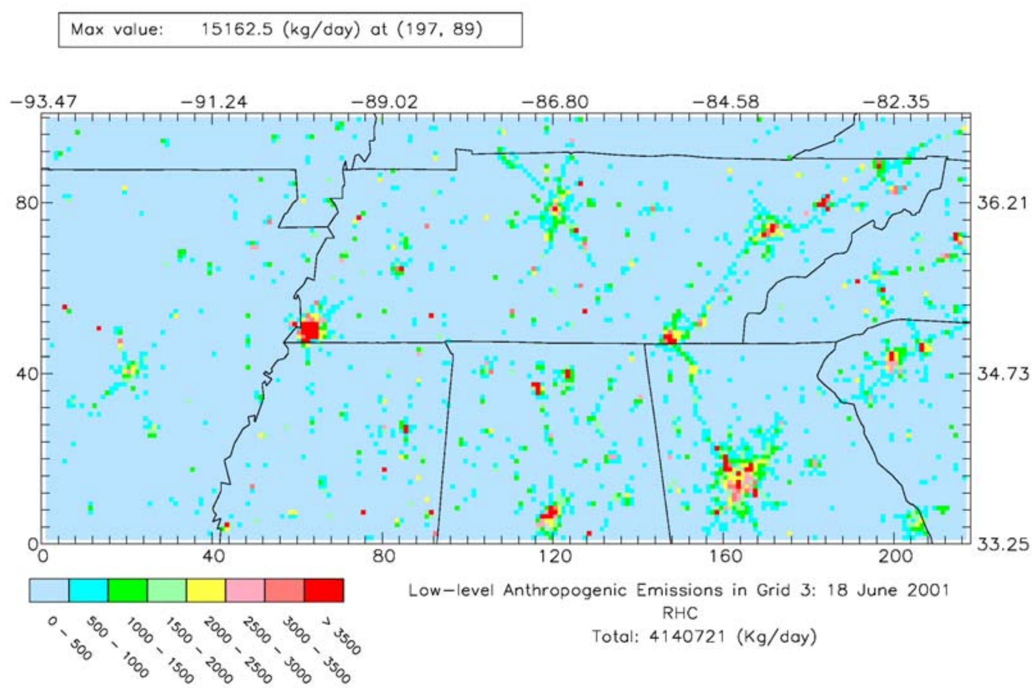


Figure 3-3a.
Elevated Point Source NO_x Emissions in Grid 1

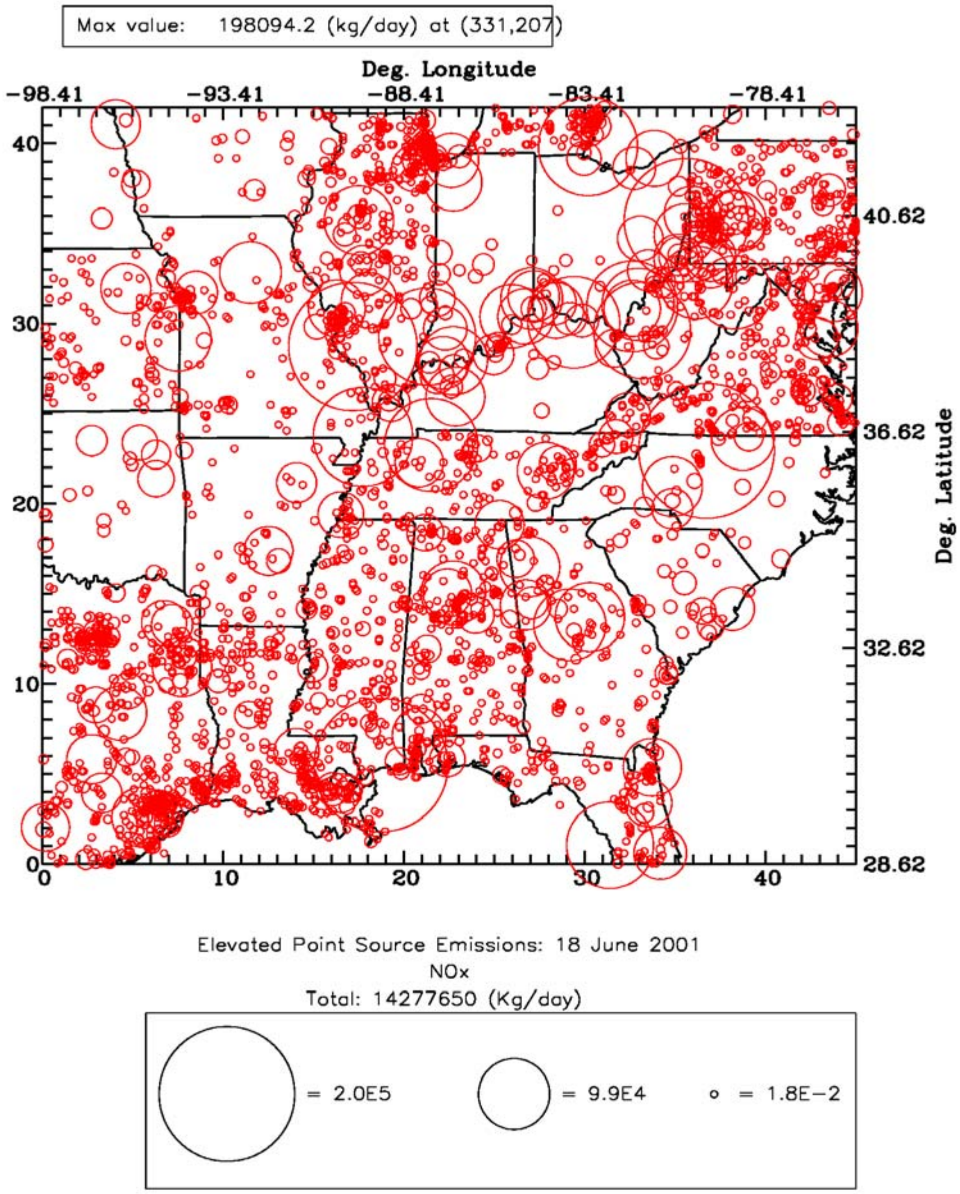
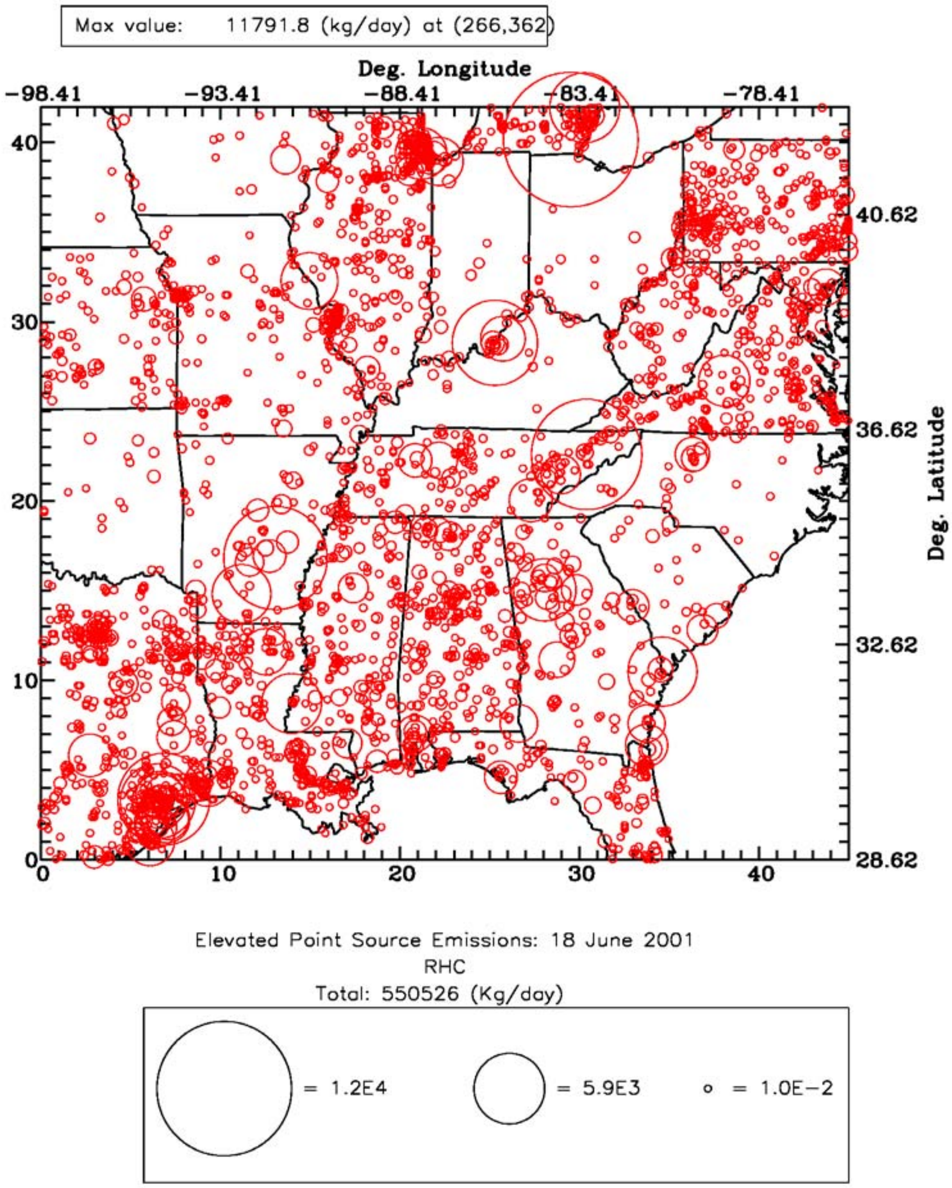


Figure 3-3b
Elevated Point Source VOC Emissions in Grid 1



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4. Meteorological Modeling and Input Preparation

The UAM-V photochemical model requires hourly, gridded input fields of wind, temperature, water-vapor concentration, pressure, vertical exchange coefficients (K_v), cloud cover, and rainfall rate. These meteorological inputs were prepared for the ATMOS UAM-V application using the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5).

MM5 is a state-of-the-science dynamic meteorological modeling system that has been used in numerous previous air quality modeling applications. Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, a detailed treatment of the planetary boundary layer, and the ability to accurately simulate features with non-negligible vertical velocity components, such as the sea breeze and terrain-generated airflows (a non-hydrostatic option). The MM5 modeling system is widely used for meteorological research and air quality modeling studies and is currently supported by NCAR.

The MM5 application procedures and results are presented in this section of the report. For ease of reading all tables and figures follow the text of this section.

Overview of the Meteorological Modeling Procedures

MM5 Application Procedures

A general description of this three-dimensional, prognostic meteorological model is found in Anthes and Warner (1978); many of the new features are described by Dudhia et al. (2001). Version 3 of MM5 was used.

For this application, the MM5 modeling system was applied for a nested-grid modeling domain that encompasses the UAM-V modeling domain as shown in Figure 1-2. The MM5 modeling domain as shown in Figure 1-3 consists of an extended outer grid with approximately 108 km horizontal resolution and three inner (nested) grids with approximately 36, 12, and 4 km resolution. The inner grids encompass the UAM-V grids with the same resolution. A one-way nesting procedure in which information from the simulation of each outer grid was used to provide boundary conditions for the inner grids was employed.

The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights (the half sigma layers) for application of MM5 are listed in Table 1-2.

To facilitate the realistic simulation of processes within the atmospheric boundary layer, the MRF high-resolution PBL scheme was employed. This scheme is compatible with the UAM-V formulation and requirements for specification of vertical exchange coefficients (as discussed below). The PBL parameterization also requires use of a multi-layer soil temperature model (an otherwise optional feature of MM5). The RRTM radiative scheme was used for the MM5 application.

For the coarser grids specified for this application, the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch, 1990) was used to parameterize the effects of convection on the simulated environment. This feature was not employed for the high-resolution (4-km) grid where an explicit moisture scheme was used.

For this study, three-dimensional analysis nudging was used to promote agreement between the observed data and the simulation results. Using this approach the simulated variables are relaxed or “nudged” toward an objective analysis that incorporates the observed data. The nudging coefficients were specified to achieve moderate nudging of the wind and temperature fields (2.5×10^{-4} or 1×10^{-4}, depending on the grid scale) and weaker to moderate nudging of moisture fields (1×10^{-5} to 5×10^{-5}) toward the observational analyses.

Vertical exchange coefficients (K_vs) for input to UAM-V were extracted directly from the MM5 model. Our version of the MM5 modeling system included the output of the internally calculated vertical exchange coefficients (K_v), as calculated using the MRF PBL scheme. These values are written to a separate MM5 output file. The K_v values for this scheme are intended to represent non-local or multi-scale diffusion coefficients (rather than local diffusion coefficients) and are therefore most suitable for use with the UAM-V modeling system. The K_v values were used to specify the vertical exchange coefficients required by the UAM-V modeling system. The direct use of the MM5-derived K_v values avoids the need to calculate the K_vs outside of MM5, and use of the various assumptions that are required for these calculations. Our prior testing of several schemes showed this scheme to be the best choice for combined MM5/UAM-V modeling.

For each simulation period, the model was initialized at 0000 GMT on the first day of the period. Thus, each MM5 simulation period includes a five-hour initialization period, before the output was used to prepare inputs for the UAM-V model. For the three outer grids, the MM5 was run continuously for the multi-day simulation period. For the higher-resolution grid, the model was reinitialized after each three days of simulation. Each re-initialization also included an additional 5-hour initialization period. Re-initialization was necessary to avoid the build up of non-meteorological noise in the simulation results that tended to occur after approximately 3 to 3 ½ days of simulation. The input fields from each simulation were inspected to ensure that piecing together the simulations did not create discontinuities in the meteorological inputs (the use of FDDA will alleviate this possibility). In any event, the junctures occur at midnight—a time that is not especially important in photochemical modeling.

The time step used for the simulations ranged from several minutes for the outermost (approximately 108 km) grid to 9 -12 seconds for the innermost (approximately 4 km) grid.

The data for preparation of the terrain, initial and boundary condition, and FDDA input files for this application were obtained from NCAR. The MM5 input files were prepared using the preprocessor programs that are part of the MM5 modeling system (Gill, 1992).

Meteorological data for the application of MM5 were also obtained from NCAR. These include the National Center for Environmental Prediction (NCEP) global analysis and surface and upper air wind, temperature, moisture, and pressure data for all routine monitoring sites within the domain. The sites include National Weather Service (NWS) sites, buoys, and a few international monitoring sites. Sea-surface temperature data were also obtained from NCAR. These data comprise the standard data set for application of the MM5 modeling system and were used for data assimilation as well as for the evaluation of the modeling results.

Preparation of UAM-V Ready Meteorological Fields

Following the application of MM5, the simulation results were plotted and reviewed using a variety of graphical and statistical analysis tools. We reviewed static plots of wind, temperature, specific humidity, vertical exchange coefficients, cloud-cover, and rainfall for selected domains, hours, and vertical levels. The number and type of plots varied by episode day, as needed to assess various aspects of the episode-specific meteorological conditions. The output was also examined using a view/animation graphics tool designed for use with MM5. At this stage the MM5 results were also compared visually and statistically with observed wind, temperature, and moisture data—to identify geographical areas or time periods for which the model output did not represent the data well and as a check on the effectiveness of the data assimilation.

The MM5 output was then postprocessed to correspond to the UAM-V modeling domain and the units and formats required by the modeling system, using the MM52UAMV postprocessing software. Wind, temperature, water-vapor concentration, pressure, vertical exchange coefficient, cloud-cover, and rainfall-rate input files containing hourly, gridded estimates of these variables were derived from the MM5 output. Surface temperature and solar radiation were postprocessed for use in preparing the biogenic emissions estimates.

Discussion of Procedures Used to Diagnose and Correct Problems and Improve Meteorological Fields

There are no specific criteria as to what constitutes an acceptable set of meteorological inputs for photochemical modeling. For this study, we relied on comparison with observed meteorological data and achievement of reasonable UAM-V simulation results to guide our diagnosis and correction of problems and to improve the meteorological fields.

August/September 1999

Throughout the course of the ATMOS modeling analysis for this episode, modifications were being made to the MM52UAMV postprocessing software for other applications, and updated versions of the software were applied to the wind fields for this project as they became available. Overall, the diagnostic analysis included several components:

- An additional lower layer (25 m) was added to the vertical structure for the UAM-V ready meteorological fields in an attempt to simulate conditions in the surface layer (not applied in final fields).
- The effects of omitting land-use based minimums for the vertical diffusion coefficients were examined (not omitted in the final fields).
- The effects of omitting smoothing of the UAM-V wind fields was examined (not applied in the final fields).

- Overestimation of cloud cover for selected days was improved by re-running MM5 with different moisture nudging parameters (rain and cloud fields can have dramatic effects on the UAM-V results—primarily by affecting the K_v fields)
- The vertical diffusion coefficients were normalized, to ensure that the maximum value represented by MM5 was also represented in the UAM-V ready K_v fields
- Similarity theory was applied to estimate surface wind speed (and average winds within the lowest UAM-V model layer)

A brief discussion of each of these last three items, which were applied in the final fields follows.

In applying MM5 for the August/September 1999 simulation period, we found that the model did not adequately simulate the surface temperatures for key locations in the eastern portion of the ATMOS fine-grid modeling domain for 1-3 September. We reran the fine-grid simulation for these three days using an enhanced moisture-nudging coefficient (5×10^{-5}). Greater nudging of the moisture fields significantly improved the simulation of the temperature fields.

For each horizontal grid cell, the vertical profile of the K_vs determines the diffusive mixing within the vertical column. For this application, the K_vs were output (hourly) by MM5 for each horizontal grid cell and MM5 layer. These were then interpolated to the UAM-V layers (layer interface levels) for use by the photochemical model. To avoid excessive smoothing of the maximum MM5-derived K_v value (a possible result of interpolation), the K_v values were renormalized for each level based on the ratio of the MM5-derived maximum value and the interpolated maximum value. In this way, both the magnitude and vertical variation in K_v, as simulated by MM5, were retained in the UAM-V ready fields. In testing this technique, we found the difference between the interpolated and renormalized values to be greatest over varied terrain—where large K_v values are sometimes associated with terrain-induced vertical motions. Incorporating this modification into the meteorological inputs for the ATMOS application resulted in a slight increase in ozone at certain sites and a slight improvement in model performance. This modified postprocessing procedure was applied for all grids and was used to prepare the final base-case input fields.

Most applications of MM5, including this one, use a lowest layer for the calculation of winds that is approximately 30 to 40 m above ground level (this varies in accordance with the pressure-based sigma coordinate system). On the other hand, the lowest UAM-V layer is typically 50 m in thickness and the wind speeds for this layer are intended to represent approximately 25 m above ground. For this application, the MM5-derived wind speeds were adjusted using similarity theory (e.g., as described by Panofsky and Dutton, 1984) to better represent the winds at the 25 m level. Using this approach, the wind speed profile within the surface layer is estimated based on similarity theory—which accounts for the effects of turbulence on atmospheric variables within the lowest portion of the atmospheric boundary layer. The MM5-derived speed is then adjusted (based on this profile) to represent the wind speed at the 25 m level. The result is a slight reduction in wind speed for the lowest UAM-V layer (compared to a straight mapping of the MM5 wind to this layer). For this application, the effects of the wind speed adjustment on the UAM-V simulated ozone concentrations were very small. Nevertheless, this approach represents a potentially improved use of the MM5 results and was used to prepare the final base-case input fields.

June 2001 and July 2002

For the initial MM5 application for both simulation periods, we found the surface- level wind fields for the 4-km resolution grid to be relatively noisy (i.e., characterized by somewhat randomly directed winds that were sometimes or even frequently different from the observations). This occurred despite the re-initialization of the model every three days (as described above). To try to improve the stability and quality of the surface wind fields, we reran MM5 for the innermost domain with a smaller time step (9 seconds instead of 12 seconds). In a second simulation, we also increased the nudging coefficient for moisture (from 10^{-5} to $5x10^{-5}$). These two changes to the MM5 inputs reduced the noisiness and provided a better representation of the surface winds. The increased moisture nudging was also intended to improve the representation of the surface temperatures, which were overestimated in the initial simulations.

In addition, we specifically conducted some diagnostic testing of postprocessing procedures and assumptions for the wind and K_v input fields. Our standard ATMOS postprocessing procedures and assumptions (as discussed above) were used without further modification, however, in the final base-case simulations.

Presentation and Evaluation of the MM5 Results

In this section we present the MM5 results corresponding to those that were used in the final UAM-V base-year (or base-case) simulation. The plots presented here were selected to illustrate the meteorological conditions associated with the modeling episode period as well as to provide information regarding the ability of the MM5 modeling system to represent some of the key meteorological features.

In presenting the results, we first focus on transport patterns described by the wind fields. Plots of the MM5-derived upper-air wind fields are provided to illustrate transport patterns (for later interpretation of the UAM-V simulation results) and to allow a comparison of the simulated wind fields with observations. For these plots, the display time of 0700 EST was chosen based on observed data availability (this corresponds to 1200 GMT) and the vertical level of approximately 300 m was selected to illustrate regional transport patterns within the boundary layer. The MM5 plots are shown for selected/key episode days.

Plots of surface temperatures compare the simulated surface temperatures with observed values and allow a review of the diurnal profiles and day-to-day differences.

Finally, statistical measures summarize the overall ability of MM5 to represent the key meteorological parameters.

29 August–9 September 1999

The ability of the MM5 modeling system to represent the observed wind fields is illustrated for 29 August–9 September in Figure 4-1. The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid. The observed wind vectors are overplotted in bold. On a few of the days, observed data appears to be in error (note wind vector over central Oklahoma on the 30th), but in general, there is good agreement between the simulated and observed winds and the MM5 model replicates well the observed wind patterns for this level. The wind fields depict the northerly movement of Hurricane Dennis from the eastern coast of Florida on the 29th of August to over North Carolina on the 5th of September. For the 29th and the 30th, the winds are primarily northeasterly. Hurricane Dennis is well defined off the eastern coast of

Georgia/South Carolina. Wind fields for 31 August through 2 September are characterized by clockwise circulation at this level. Northeasterly and easterly components dominate the wind field on the 3rd. Hurricane Dennis again appears in the wind fields of the 4th, off the South Carolina/North Carolina coast and moves onshore over North Carolina on the 5th. Counter-clockwise circulation associated with Hurricane Dennis is the major feature in the wind fields on the 5th. A northerly wind component dominates the winds on the 6th . The remains of the hurricane is evident over the northeastern portion of the domain on this day also. Winds on the 7th are weaker and continued northerly. On the 8th, winds are very light over Tennessee at this level, and evidence of a high pressure system is indicated by the clockwise circulation over western Tennessee. Winds on 9 September are also generally from the north and northwest.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-2. Observed temperatures are generally well simulated by the model. Notable exceptions do however occur. Maximum temperatures are overestimated at the Memphis site on the 2nd of September and underestimated at Chattanooga on the same day.

MM5-derived mixing heights are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-1. The MM5-derived values were estimated from the vertical exchange coefficient (K_v) profiles, an example of which is presented in Figure 4-3. This figure shows the K_v profile for Nashville for 0900, 1200, 1500, and 1800 CST on 31 August. From these plots, the mixing height is estimated to be the level at which the value of K_v drops to ten percent of its maximum value. The example profiles exhibit expected vertical distributions and indicate that the maximum effective mixing heights are approximately 700 m at 0900 CST, 1200 m at 1200 CST, 1625 m at 1500 CST, and 0 m at 1800 CST. The corresponding values from the upper-air sounding were estimated from the temperature soundings by extending a line with a constant temperature lapse rate equal to the dry adiabatic lapse rate upward from the surface temperature. The intersection with the temperature sounding is the observation-based mixing height. This simple method for estimating mixing heights is not expected to give reliable values when the upper air temperature structure changes significantly during the day. Thus, this comparison is intended only to provide qualitative information as to the reasonableness of the MM5-derived mixing height values.

A comparison of the MM5-based and observation-based values in Table 4-1 for 1500 CST shows that for those days for which reliable estimates could be obtained using both methods, the MM5-based mixing heights are both higher and lower than the observation-based estimates. The values for MM5 appear reasonable and are more consistent day-to-day than the observation based values. The MM5-derived estimates are lower than the observation-based values by about 20 –25 percent for 29 August and 1-2 September, and considerably higher than the observation-based estimate for 6 September. Since we are comparing two different results from two different methodologies, this comparison cannot be used directly to assess the quality of the MM5 fields, as there are two many uncertainties inherent in both estimates. This comparison was conducted in order that it might provide perspective later in the modeling analysis, especially regarding the over or underestimation of ozone on certain days.

Statistical summaries of the MM5 results are presented in Table 4-2. Daily values of the mean simulated and observed values for temperature, specific humidity, wind direction and wind speed are presented along with the calculated mean residual. The residuals were calculated by comparing the MM5 results with observed data, and represent averages for the 4-km or innermost MM5 domain. The summaries are presented for the surface layer and two upper-layers. While there are more data within the surface layer, there is a mismatch between the model level and the level at which the measurements are taken. For winds, the difference in height of the simulated and observed values is about 20 m. For temperature and specific humidity, the difference is about 25 m. We did not adjust for these differences, thus, some difference between the simulated and observed values for the surface layer is expected.

The statistical measures indicate that the mean values of all parameters are generally well represented by MM5 for all simulation days. Surface temperatures are underestimated on average by about 0.5 to 1.5 degrees at the surface and well represented at the upper levels. There is some tendency for underestimation of the specific humidity, but the bias is small. Surface wind speeds are generally overestimated by MM5, but the bias is typically less than 1 ms^{-1}, with some exceptions. In some cases, the overestimation of wind speed carries upward to the 300 m layer. Wind directions are well represented aloft (with a bias of less than 20 degrees) and less well represented near the surface—likely due to the very low wind speeds. A bias on the order of 10 to 30 degrees characterizes the agreement with the surface winds. Under low wind speed conditions, such as those that characterize this episode period, the errors in wind direction are not very meaningful.

In summary, the MM5 results for the 29 August to 9 September modeling episode period represent observed conditions well.

16–22 June 2001

The ability of the MM5 modeling system to represent the observed wind fields is illustrated for 16–22 June 2001 in Figure 4-4. The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid. The observed wind vectors are overplotted in bold. In general, there is good agreement between the simulated and observed winds and the MM5 model replicates well the observed wind patterns for this level.

The simulation period begins with a high-pressure system over Little Rock that is manifested in the wind fields by an anticyclonic flow pattern. Winds over Tennessee are from the north. As the system migrates northeastward, the winds over Tennessee become easterly by the 18th, and then southerly by the following day. Finally westerly to northwesterly winds develop on the 22nd as a cold front moves through Arkansas and into Tennessee.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-5. The simulated values are very well simulated. The diurnal profiles and day-to-day differences in the profiles are well represented at all sites, especially considering the last one or two (depending on the site) simulation days.

MM5-derived mixing height are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-3. At 1500 CST, MM5-based mixing heights are generally lower than observation-based values. This is especially true for 19 and 20 June. However, since we are comparing two different results from two different methodologies, this comparison cannot be used directly to assess the quality of the MM5 fields, as there are two many uncertainties inherent in both estimates. This comparison was conducted in order that it might provide perspective later in the modeling analysis, especially regarding the over or underestimation of ozone on certain days.

Statistical summaries of the MM5 results are presented in Table 4-4. The statistical measures indicate that the mean values of all parameters are generally represented by MM5 for all simulation days. Temperatures are overestimated on average by about 0.5 to 1 degrees at all levels. There is some tendency for underestimation of the specific humidity, but the bias is small. The very light wind speeds that characterize the surface fields for all days are overestimated by MM5. There is also some overestimation of wind speeds aloft for the 19th and 20th. The bias in wind speed is typically less than 1 ms^{-1}, with some exceptions. Wind directions are well represented aloft (with a bias of less than 10 degrees) and less well represented near the surface—likely due to the very low wind speeds. A bias on the order of 10 to 20 degrees characterizes the agreement with the surface winds. Under low wind speed conditions, such as those that characterize this episode period, the bias in wind direction is not very meaningful.

In summary, the MM5 results for the June 2001 modeling episode period represent observed conditions well.

4–10 July 2002

The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid in Figure 4-6. The observed wind vectors are overplotted in bold. In general, there is good agreement between the simulated and observed wind fields for this level. For some days, the MM5 wind speeds are higher than observed.

The simulation period begins with a convergence zone over Tennessee on the 4th, with northeasterly winds in the eastern part of the state and northerly to westerly winds in the western part of the state and into Arkansas. There is some disagreement with the observed winds for the hour and level shown in the plot. The wind direction shifts to northeasterly on the 5th and remains easterly to northeasterly through the 7th. This is followed by a transition to southeasterly, southerly and then southwesterly on the 8th and 9th. Westerly winds on the 10th mark the end of the ozone episode through the domain. The transition to westerly flow takes place earlier further aloft. The evolution of the airflow patterns is similar in many respects to those for June 2001 simulation period as well as to the first part of the August/September 1999 simulation periods and is driven by the west-to-east migration of a high pressure system across the domain.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-7. Underestimation occurs at Nashville on the 8th and at Chattanooga on the 6th and 10th. Otherwise, the diurnal profiles and day-to-day differences in the profiles are well represented at all sites, especially considering the last one or two (depending on the site) simulation days.

MM5-derived mixing height are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-5. A comparison of the MM5-based and observation-based values in Table 4-5 shows that MM5-based mixing heights at 1500 CST MM5-based mixing heights appear reasonable and are quite similar to observation-based values several of the days. The MM5-derived values are lower than the observation-based estimates on the 8th and higher on the 9th. The MM5-derived values are also more consistent day-to-day than the observation-based values.

Statistical summaries of the MM5 results for the July 2002 episode period are presented in Table 4-6. The statistical measures indicate that the mean values of all parameters are well represented by MM5 for all simulation days and all levels. Temperatures are overestimated on average by about 1 to 2 degrees at the surface with smaller differences aloft. This episode is more humid than the June 2001 episode and the higher specific humidities are well represented; the bias is small (generally less than 1 gkg^{-1}). As for the June 2001 simulation period, the light wind speeds that characterize the surface fields for all days are overestimated by MM5. There is also some overestimation of wind speeds aloft for several of the simulation days. The bias in wind speed is typically less than 1 ms^{-1}, with some exceptions. Wind directions are well represented aloft (with a bias of less than 10 degrees) and less well represented near the surface—likely due to the low wind speeds. A bias on the order of 10 to 20 degrees quantifies the agreement with the surface winds for most days. Under low wind speed conditions, such as those that characterize this episode period, the errors in wind direction are not very meaningful.

In summary, the MM5 results for the July 2002 modeling episode period represent observed conditions well.

Quality Assurance of the Meteorological Inputs

The MM5 results were evaluated using mostly graphical analysis. The overall evaluation of the MM5 results included the following elements. For the outer grids, examination of the MM5 output focused on representation of the regional-scale meteorological features and airflow patterns and included a comparison with weather maps. A more detailed evaluation of the results for the inner (high-resolution) grid emphasized representation of the observed data, terrain-induced and other local meteorological features, and vertical mixing parameters. To the extent possible, the modeling results were compared with observed data. In the absence of data (e.g., for unmonitored areas and for not-measured parameters such as K_v), the MM5 results were examined for physical reasonableness as well as spatial and temporal consistency.

Comparison with the observed data was primarily used to examine the model's ability to represent key meteorological features such as the wind speeds as directions aloft and site-specific temperatures. The UAM-V ready meteorological inputs were also plotted and examined to ensure that the characteristics and features present in the MM5 output were retained following the postprocessing step. The ability of the MM5 model to reproduce observed precipitation patterns was qualitatively assessed by comparing the simulated and observed rainfall patterns (based on NWS data)—some rainfall occurred during the episode periods and this was reflected in the MM5.

The following graphical summaries were prepared to facilitate the review/evaluation of the meteorological inputs:

- 3-dimensional visualizations of the MM5 output using the Environmental WorkBench software (an enhanced version of VIS-5D).
- x-y cross-section plots of the MM5 wind fields for several levels and times with observations overplotted for MM5 Grids 1, 2, and 3.
- x-y cross-section plots of the UAM-V ready wind, temperature, vertical exchange coefficient, cloud-cover, and rainfall-rate fields for several times and levels (as appropriate).

On two occasions during the course of the modeling analysis, we enhanced the MM5 to UAM-V software for other applications, and re-processed the fields using enhanced versions of the software.

Finally, the process analysis feature of UAM-V was also used for the August/September 1999 simulation period to further examine the role of the meteorological inputs in determining the simulated concentration patterns and levels (and their contribution to good or poor model performance). The role of meteorology in the diagnostic analysis for UAM-V is discussed in more detail in Section 6.

Table 4-1.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 29 August–09 September 1999

Date	1500 CST	
	MM5 Derived	Observation Derived
29 August	1629	2085
30 August	1211	NA*
31 August	1570	1420
1 September	1630	2125
2 September	1558	2010
3 September	1568	1775
4 September	1631	NA
5 September	1630	NA
6 September	1583	805
7 September	1240	1090
8 September	NA	NA
9 September	1584	NA

* NA indicates that a reliable estimate could not be derived.

Table 4-2a.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 29 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.5	299.2	-0.7
300 m	298.2	298.3	-0.1
1200 m	292.6	292.5	0.2
Specific Humidity (gkg-1)			
Surface	14.6	13.4	1.2
300 m	14.1	13.0	1.1
1200 m	12.0	11.0	1.0
Wind Direction (degrees)			
Surface	37.7	31.0	7.6
300 m	41.1	34.5	2.6
1200 m	46.3	42.9	2.8
Wind Speed (ms-1)			
Surface	3.8	2.4	1.3
300 m	7.0	5.9	0.7
1200 m	7.0	5.9	0.7

Table 4-2b.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
30 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	296.8	297.4	-0.6
300 m	295.0	296.1	-1.0
1200 m	295.0	296.1	-1.0
Specific Humidity (gkg-1)			
Surface	10.3	10.0	0.3
300 m	10.3	10.1	0.2
1200 m	9.2	9.0	0.2
Wind Direction (degrees)			
Surface	39.4	33.6	9.3
300 m	37.8	29.3	10.1
1200 m	32.8	24.6	13.2
Wind Speed (ms-1)			
Surface	5.1	3.5	1.6
300 m	8.6	6.0	2.2
1200 m	8.7	9.0	-0.2

Table 4-2c.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
31 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	294.4	294.8	-0.4
300 m	293.5	293.3	0.2
1200 m	289.8	289.7	0.0
Specific Humidity (gkg-1)			
Surface	8.5	8.2	0.3
300 m	7.5	7.4	0.1
1200 m	6.0	6.1	-0.1
Wind Direction (degrees)			
Surface	69.1	64.7	8.2
300 m	61.0	61.6	4.9
1200 m	48.4	41.0	21.9
Wind Speed (ms-1)			
Surface	3.3	1.9	1.1
300 m	5.0	4.6	-0.7
1200 m	4.1	2.9	-0.3

Table 4-2d.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 1 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	295.8	296.4	-0.6
300 m	295.7	296.2	-0.5
1200 m	291.6	291.4	0.2
Specific Humidity (gkg-1)			
Surface	11.0	10.2	0.7
300 m	9.8	8.8	1.0
1200 m	7.5	7.4	0.2
Wind Direction (degrees)			
Surface	85.0	65.6	26.0
300 m	44.2	37.1	3.1
1200 m	19.8	8.5	4.3
Wind Speed (ms-1)			
Surface	0.9	0.3	0.5
300 m	1.8	1.2	-0.6
1200 m	3.3	3.4	-0.7

Table 4-2e.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 2 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.7	297.9	-0.2
300 m	297.4	298.0	-0.6
1200 m	292.6	292.8	-0.2
Specific Humidity (gkg-1)			
Surface	11.9	11.2	0.7
300 m	10.0	9.4	0.5
1200 m	7.9	7.4	0.5
Wind Direction (degrees)			
Surface	57.7	42.9	15.4
300 m	40.0	19.0	-15.4
1200 m	39.3	29.6	8.3
Wind Speed (ms-1)			
Surface	0.8	0.5	0.3
300 m	2.3	2.6	-0.5
1200 m	4.2	3.6	-0.2

Table 4-2f.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
3 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.9	298.7	-0.8
300 m	297.6	297.8	-0.3
1200 m	292.7	292.7	0.0
Specific Humidity (gkg-1)			
Surface	11.8	11.3	0.5
300 m	10.6	10.2	0.4
1200 m	8.6	8.5	0.1
Wind Direction (degrees)			
Surface	62.3	47.4	17.8
300 m	59.4	48.5	16.2
1200 m	60.9	51.8	9.8
Wind Speed (ms-1)			
Surface	1.8	1.1	0.7
300 m	3.3	3.1	-0.1
1200 m	4.9	5.1	-0.9

Table 4-2g.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
4 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.4	298.7	-1.3
300 m	297.3	297.5	-0.2
1200 m	292.2	292.2	0.0
Specific Humidity (gkg-1)			
Surface	12.2	11.7	0.5
300 m	11.5	12.3	-0.9
1200 m	10.7	10.3	0.5
Wind Direction (degrees)			
Surface	29.3	11.9	19.0
300 m	10.5	7.2	-5.1
1200 m	21.4	20.2	4.6
Wind Speed (ms-1)			
Surface	1.4	0.8	0.7
300 m	4.1	4.3	-0.9
1200 m	5.0	4.9	-1.1

Table 4-2h.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
5 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.2	298.7	-1.5
300 m	296.5	296.0	0.6
1200 m	292.1	292.1	0.1
Specific Humidity (gkg-1)			
Surface	13.2	12.9	0.3
300 m	13.1	12.4	0.7
1200 m	11.7	11.0	0.6
Wind Direction (degrees)			
Surface	315.0	307.5	31.8
300 m	354.7	349.1	12.4
1200 m	1.7	0.3	9.4
Wind Speed (ms-1)			
Surface	2.8	1.9	0.7
300 m	5.1	5.2	-0.6
1200 m	4.4	5.8	-2.9

Table 4-2i.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
6 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.4	298.9	-0.5
300 m	297.1	297.6	-0.4
1200 m	292.8	292.9	-0.1
Specific Humidity (gkg-1)			
Surface	12.7	13.1	-0.4
300 m	13.0	13.1	-0.1
1200 m	10.3	10.9	-0.6
Wind Direction (degrees)			
Surface	318.7	328.3	35.3
300 m	303.7	267.7	14.5
1200 m	306.1	288.8	5.2
Wind Speed (ms-1)			
Surface	2.5	1.0	1.2
300 m	2.6	2.6	0.0
1200 m	3.3	4.3	-1.0

Table 4-2j.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 7 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.2	298.4	-1.2
300 m	297.9	298.6	-0.6
1200 m	293.4	293.7	-0.3
Specific Humidity (gkg-1)			
Surface	12.9	12.4	0.5
300 m	12.5	12.5	0.0
1200 m	10.5	10.5	0.0
Wind Direction (degrees)			
Surface	126.6	153.7	6.4
300 m	194.9	219.0	-8.8
1200 m	259.2	276.9	1.4
Wind Speed (ms-1)			
Surface	0.5	0.5	0.7
300 m	1.3	1.2	0.4
1200 m	2.0	2.5	-0.7

Table 4-2k.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 8 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.4	297.8	-0.4
300 m	297.3	297.5	-0.1
1200 m	292.5	292.3	0.2
Specific Humidity (gkg-1)			
Surface	12.6	12.7	-0.1
300 m	11.2	12.3	-1.1
1200 m	9.2	9.8	-0.6
Wind Direction (degrees)			
Surface	223.1	281.3	31.7
300 m	307.9	273.1	15.1
1200 m	313.5	291.9	20.1
Wind Speed (ms-1)			
Surface	0.2	0.4	0.3
300 m	0.8	1.3	-0.6
1200 m	1.5	2.6	-0.9

Table 4-2l.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 9 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	295.5	296.1	-0.6
300 m	294.4	293.7	0.7
1200 m	290.9	290.7	0.2
Specific Humidity (gkg-1)			
Surface	11.6	11.5	0.2
300 m	10.8	10.2	0.6
1200 m	6.9	8.9	-2.0
Wind Direction (degrees)			
Surface	353.6	338.3	38.6
300 m	19.3	20.6	-4.8
1200 m	19.8	22.4	-18.2
Wind Speed (ms-1)			
Surface	2.0	1.3	0.7
300 m	3.5	4.2	-1.0
1200 m	3.5	3.4	-0.1

Table 4-3.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 16-22 June 2001

Date	1500 CST	
	MM5 Derived	Observation Derived
16 June	1196	1590
17 June	1613	1700
18 June	1194	1500
19 June	1146	2500
20 June	1161	2275
21 June	NA*	2550
22 June	1193	950

* NA indicates that a reliable estimate could not be derived.

**Table 4-4a.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
16 June 2001**

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.2	297.5	0.8
300 m	296.9	297.0	-0.1
1200 m	290.6	289.9	0.7
Specific Humidity (gkg-1)			
Surface	12.1	12.2	-0.1
300 m	11.1	11.2	-0.1
1200 m	8.0	8.6	-0.6
Wind Direction (degrees)			
Surface	311.7	305.6	22.3
300 m	334.2	320.9	14.8
1200 m	349.9	331.7	13.7
Wind Speed (ms-1)			
Surface	1.9	1.0	1.1
300 m	4.2	4.5	0.1
1200 m	5.1	4.7	0.7

**Table 4-4b.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
17 June 2001**

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	299.0	298.2	0.9
300 m	297.7	297.6	0.1
1200 m	291.7	291.0	0.6
Specific Humidity (gkg-1)			
Surface	10.3	11.5	-1.1
300 m	9.1	9.5	-0.4
1200 m	6.2	7.0	-0.8
Wind Direction (degrees)			
Surface	23.2	24.9	9.4
300 m	22.2	18.4	3.0
1200 m	38.1	33.1	8.4
Wind Speed (ms-1)			
Surface	1.2	0.4	1.1
300 m	3.2	3.5	-0.5
1200 m	4.9	4.5	0.2

Table 4-4c.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 18 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	299.4	298.5	0.9
300 m	298.0	298.1	-0.1
1200 m	291.2	291.0	0.2
Specific Humidity (gkg-1)			
Surface	11.9	11.9	-0.1
300 m	10.2	10.5	-0.2
1200 m	8.1	8.3	-0.2
Wind Direction (degrees)			
Surface	134.4	153.2	-3.1
300 m	116.7	103.3	12.0
1200 m	123.3	119.5	-7.0
Wind Speed (ms-1)			
Surface	2.1	1.4	1.3
300 m	4.2	4.2	-0.3
1200 m	5.0	4.1	0.9

Table 4-4d.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 19 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.9	298.4	0.5
300 m	297.2	297.5	-0.3
1200 m	290.4	290.2	0.3
Specific Humidity (gkg-1)			
Surface	11.9	12.8	-0.9
300 m	10.5	11.6	-1.1
1200 m	9.0	9.3	-0.3
Wind Direction (degrees)			
Surface	158.7	154.6	14.5
300 m	156.7	147.7	2.7
1200 m	147.7	133.4	13.5
Wind Speed (ms-1)			
Surface	2.3	1.0	1.3
300 m	4.8	3.8	0.4
1200 m	4.6	3.2	1.0

Table 4-4e.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 20 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.2	297.6	0.6
300 m	296.8	296.4	0.4
1200 m	290.4	290.0	0.4
Specific Humidity (gkg-1)			
Surface	12.3	13.4	-1.1
300 m	11.5	12.4	-0.9
1200 m	9.7	10.3	-0.7
Wind Direction (degrees)			
Surface	177.7	136.7	21.6
300 m	196.8	195.3	8.6
1200 m	215.5	197.5	-5.6
Wind Speed (ms-1)			
Surface	0.9	0.4	0.7
300 m	2.5	2.2	-0.5
1200 m	1.5	1.0	-0.2

Table 4-4f.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 21 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.3	296.7	0.6
300 m	296.3	296.3	0.1
1200 m	290.1	289.7	0.4
Specific Humidity (gkg-1)			
Surface	12.6	13.5	-0.9
300 m	11.8	13.3	-1.4
1200 m	10.2	10.7	-0.5
Wind Direction (degrees)			
Surface	250.2	255.4	20.8
300 m	230.4	242.5	4.0
1200 m	258.2	259.2	7.7
Wind Speed (ms-1)			
Surface	1.1	0.9	0.4
300 m	3.5	4.6	-1.1
1200 m	4.1	4.3	-0.3

Table 4-4g.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 22 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	289.6	288.8	0.8
300 m	294.1	293.5	0.6
1200 m	287.9	287.7	0.2
Specific Humidity (gkg-1)			
Surface	12.0	12.3	-0.3
300 m	11.2	12.2	-1.0
1200 m	9.5	9.2	0.3
Wind Direction (degrees)			
Surface	308.4	299.5	29.8
300 m	301.0	285.2	19.0
1200 m	301.0	285.2	19.0
Wind Speed (ms-1)			
Surface	1.0	0.8	0.6
300 m	2.2	3.3	-0.7
1200 m	3.0	4.3	-1.4

Table 4-5.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 04–10 July 2002

Date	1500 CST	
	MM5 Derived	Observation Derived
04 July	2037	1850
05 July	NA*	2030
06 July	1187	1050
07 July	1191	1050
08 July	1212	1930
09 July	1197	675
10 July	1205	NA

* NA indicates that a reliable estimate could not be derived.

Table 4-6a.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
4 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.2	299.4	1.9
300 m	298.5	298.3	0.2
1200 m	292.3	292.1	0.3
Specific Humidity (gkg-1)			
Surface	17.6	15.2	2.4
300 m	15.9	14.6	1.3
1200 m	12.7	12.0	0.8
Wind Direction (degrees)			
Surface	34.1	64.7	23.3
300 m	3.5	4.0	2.2
1200 m	46.0	63.1	5.8
Wind Speed (ms-1)			
Surface	0.6	0.1	0.2
300 m	0.8	0.7	-1.1
1200 m	2.5	2.0	-0.4

Table 4-6b.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
5 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	2.5	2.0	-0.4
300 m	300.0	299.9	0.2
1200 m	293.3	292.9	0.5
Specific Humidity (gkg-1)			
Surface	15.7	15.5	0.1
300 m	14.2	15.8	-1.6
1200 m	12.0	12.6	-0.6
Wind Direction (degrees)			
Surface	46.7	40.9	10.0
300 m	58.0	49.0	17.0
1200 m	60.3	64.4	-1.1
Wind Speed (ms-1)			
Surface	1.4	0.4	0.8
300 m	1.6	1.2	-0.5
1200 m	4.0	3.4	0.2

Table 4-6c.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
6 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.5	300.8	0.7
300 m	299.8	300.2	-0.5
1200 m	293.4	293.2	0.2
Specific Humidity (gkg-1)			
Surface	15.9	14.9	1.0
300 m	14.8	14.7	0.1
1200 m	11.8	12.0	-0.2
Wind Direction (degrees)			
Surface	60.7	52.1	10.7
300 m	70.4	74.7	13.6
1200 m	66.3	74.0	1.7
Wind Speed (ms-1)			
Surface	2.5	1.5	1.0
300 m	3.2	2.6	-0.4
1200 m	4.4	3.1	0.7

Table 4-6d.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
7 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	300.9	300.0	0.9
300 m	299.4	299.8	-0.4
1200 m	293.2	293.3	-0.1
Specific Humidity (gkg-1)			
Surface	14.0	14.0	0.1
300 m	14.0	14.3	-0.4
1200 m	11.5	11.8	-0.3
Wind Direction (degrees)			
Surface	89.4	80.2	9.4
300 m	95.4	80.2	9.3
1200 m	84.6	83.1	-1.6
Wind Speed (ms-1)			
Surface	2.3	1.4	0.8
300 m	4.2	3.6	0.2
1200 m	4.6	3.3	1.1

Table 4-6e.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
8 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.5	300.1	1.4
300 m	298.8	299.1	-0.2
1200 m	292.6	292.1	0.5
Specific Humidity (gkg-1)			
Surface	15.5	14.1	1.4
300 m	14.8	14.0	0.8
1200 m	11.0	11.8	-0.8
Wind Direction (degrees)			
Surface	153.5	155.1	5.6
300 m	158.7	154.8	9.6
1200 m	147.6	164.1	8.1
Wind Speed (ms-1)			
Surface	1.4	0.8	0.6
300 m	2.9	2.8	0.2
1200 m	2.4	1.7	0.9

Table 4-6f.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
9 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	302.0	300.6	1.4
300 m	299.3	299.3	0.1
1200 m	292.8	292.3	0.5
Specific Humidity (gkg-1)			
Surface	15.2	15.2	-0.1
300 m	14.7	15.0	-0.3
1200 m	12.1	12.3	-0.2
Wind Direction (degrees)			
Surface	219.3	218.5	6.4
300 m	225.3	222.4	14.8
1200 m	243.5	239.8	9.3
Wind Speed (ms-1)			
Surface	2.4	1.5	0.7
300 m	4.2	4.1	-0.7
1200 m	3.6	2.8	0.6

Table 4-6g.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 10 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.4	299.9	1.5
300 m	299.1	298.8	0.4
1200 m	292.9	292.7	0.2
Specific Humidity (gkg-1)			
Surface	16.1	15.9	0.2
300 m	14.9	15.3	-0.4
1200 m	12.9	12.5	0.4
Wind Direction (degrees)			
Surface	245.4	241.0	32.6
300 m	251.8	253.4	5.2
1200 m	251.8	253.4	5.2
Wind Speed (ms-1)			
Surface	1.5	1.0	-0.2
300 m	3.6	4.1	-1.3
1200 m	3.8	4.2	-0.4

Figure 4-1a.
MM5-Derived 12-km Wind Field for 0700 EST on 29 August 1999
at Approximately 300 m agl

Observations are overplotted in bold

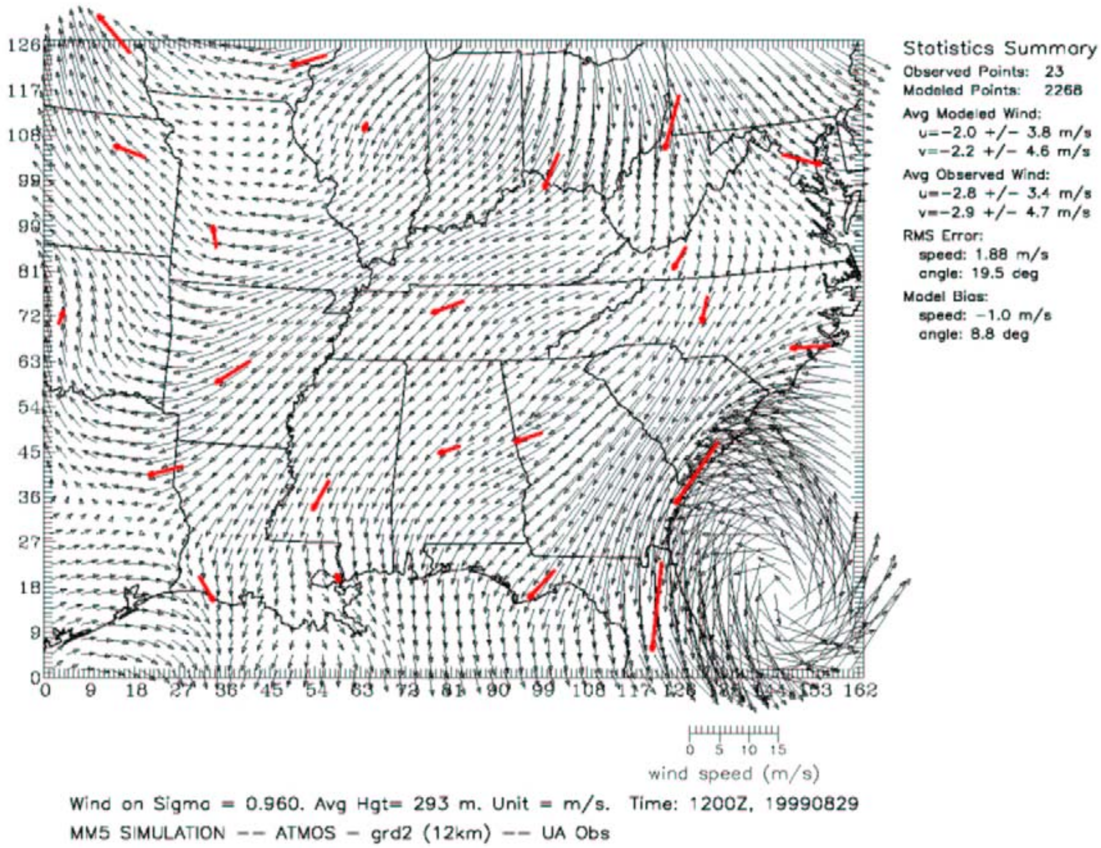


Figure 4-1b.
MM5-Derived 12-km Wind Field for 0700 EST on 30 August 1999
at Approximately 300 m agl.

Observations are overplotted in bold

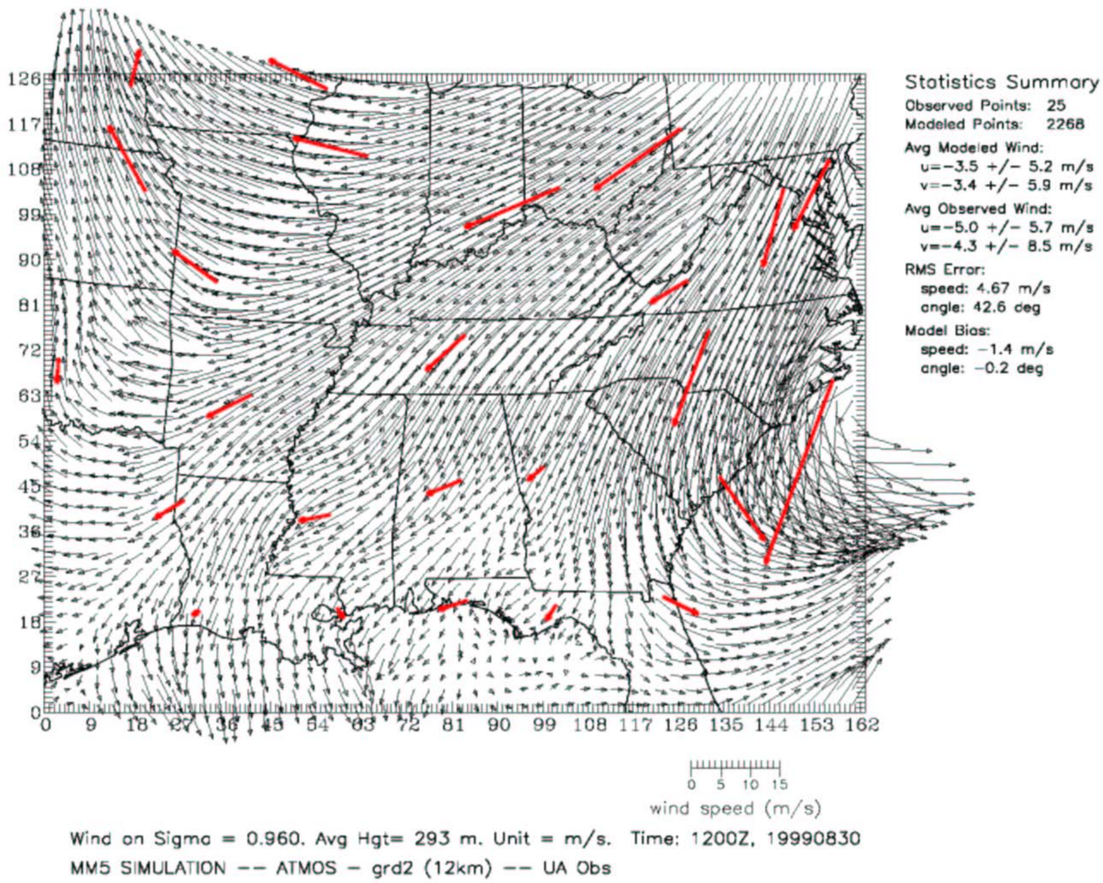


Figure 4-1c.
MM5-Derived 12-km Wind Field for 0700 EST on 31 August 1999
at Approximately 300 m agl.

Observations are overplotted in bold

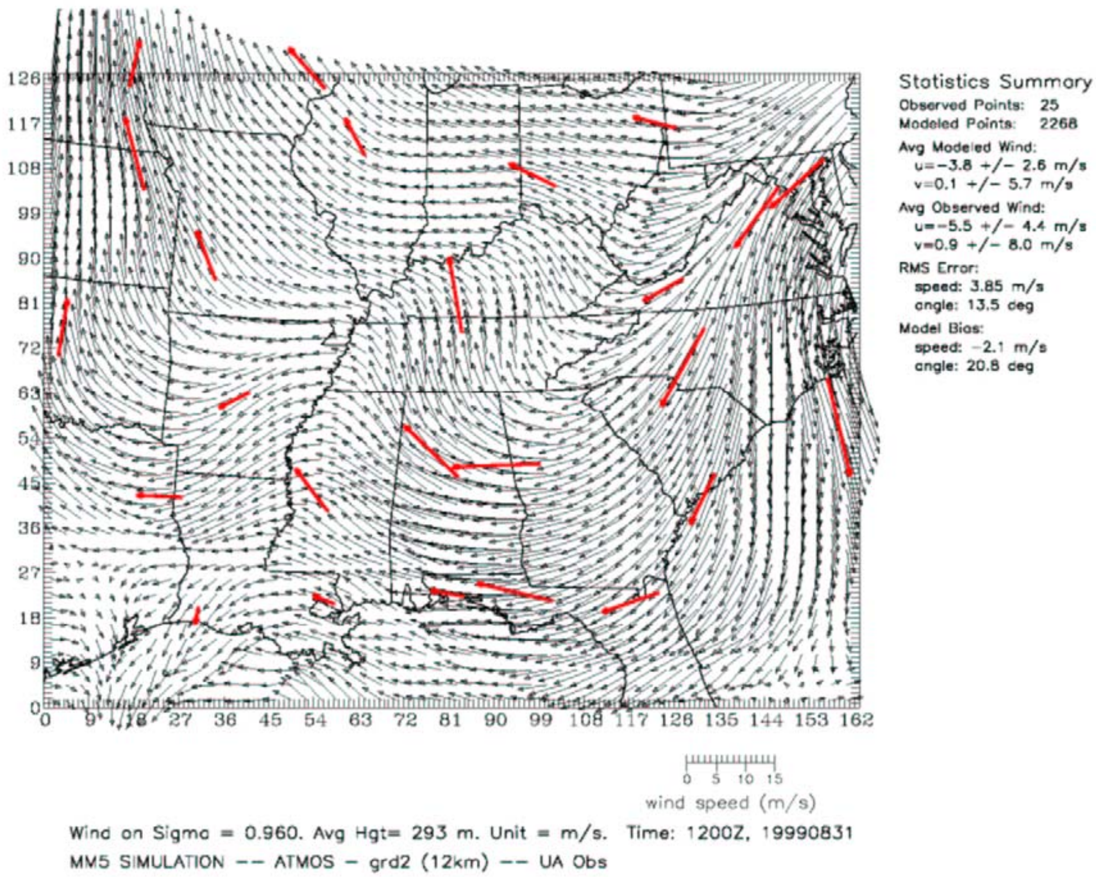


Figure 4-1d.
MM5-Derived 12-km Wind Field for 0700 EST on 1 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

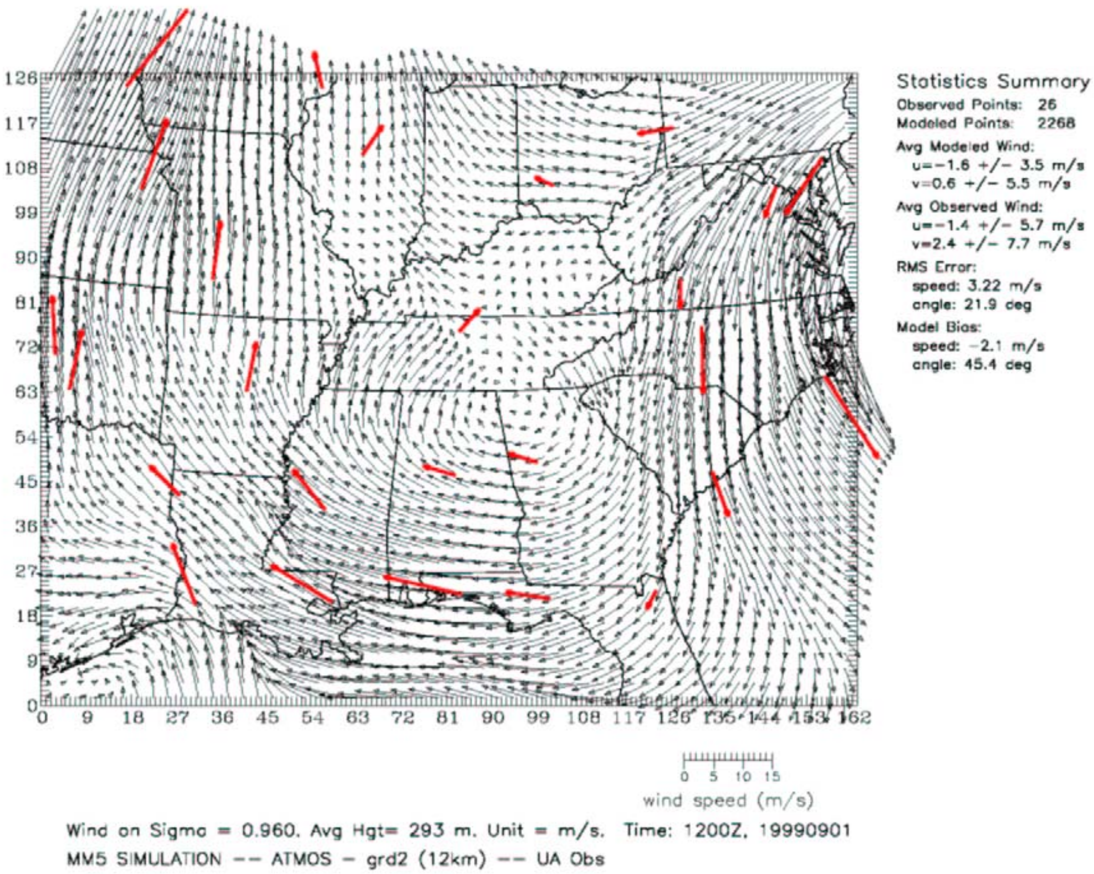


Figure 4-1e.
MM5-Derived 12-km Wind Field for 0700 EST on 2 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

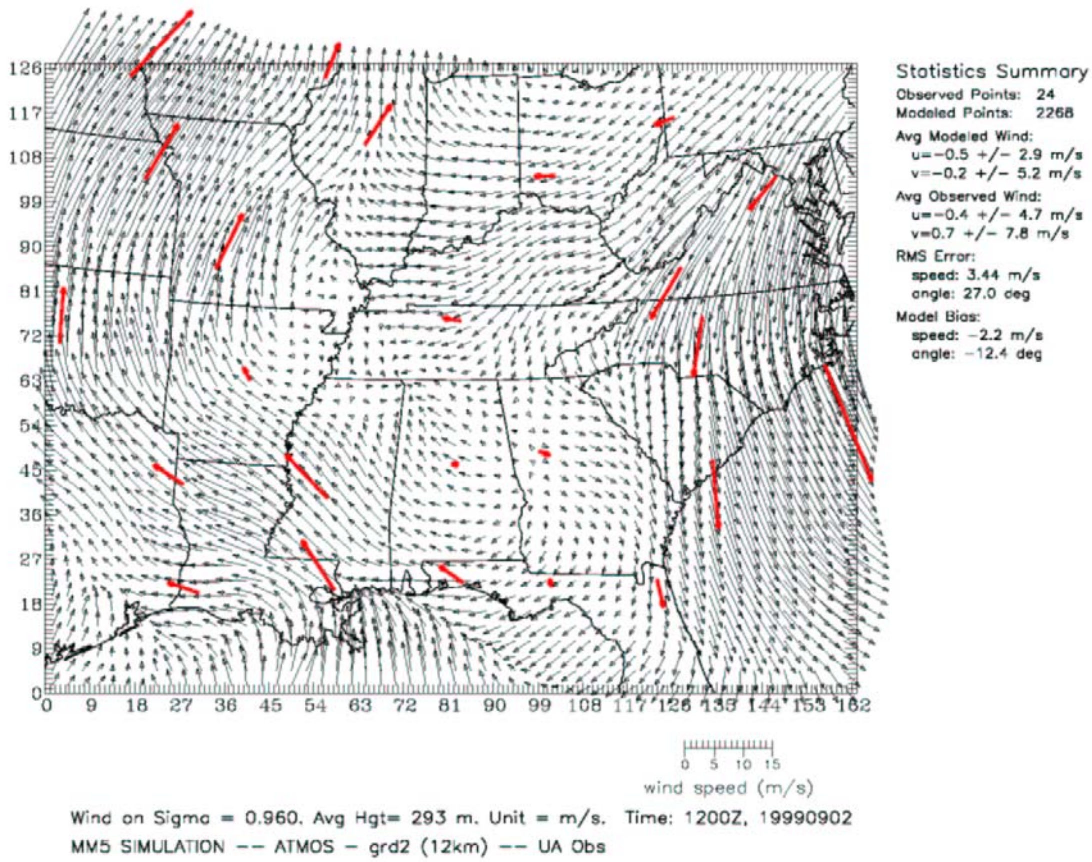


Figure 4-1f.
MM5-Derived 12-km Wind Field for 0700 EST on 3 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

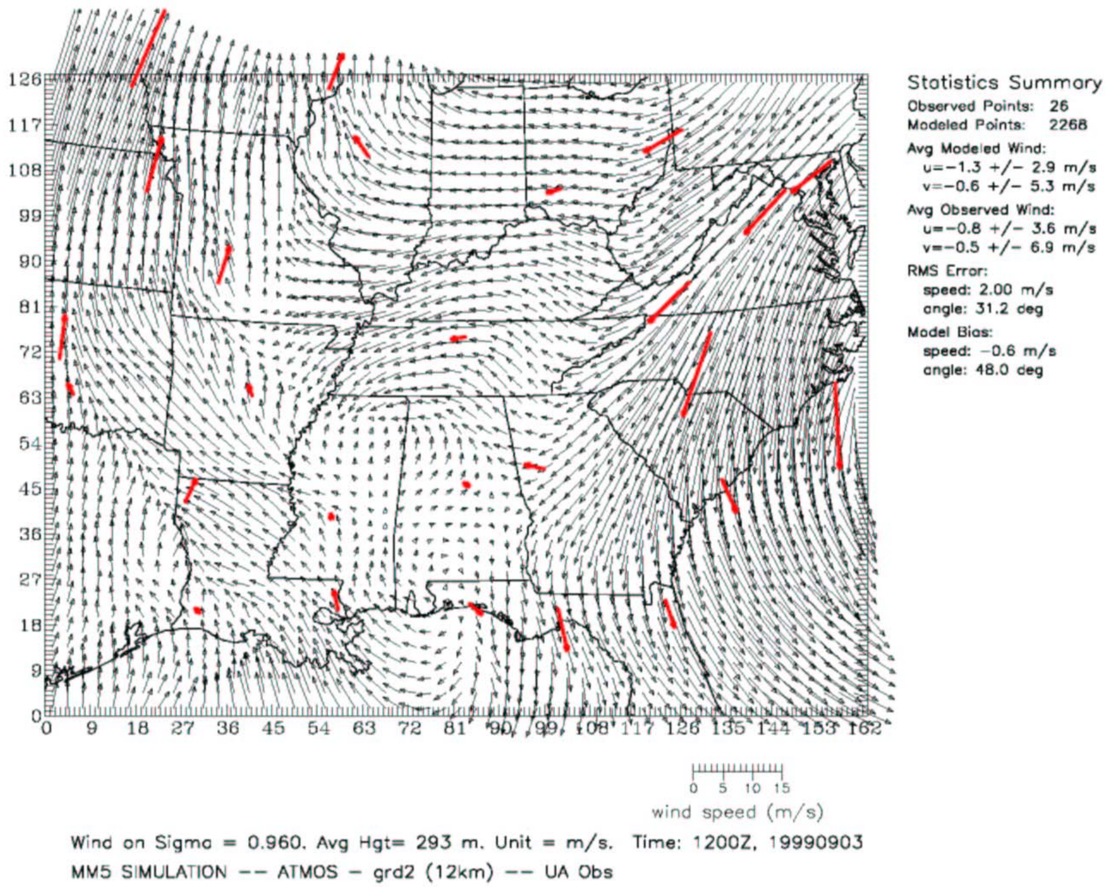


Figure 4-1g.
MM5-Derived 12-km Wind Field for 0700 EST on 4 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

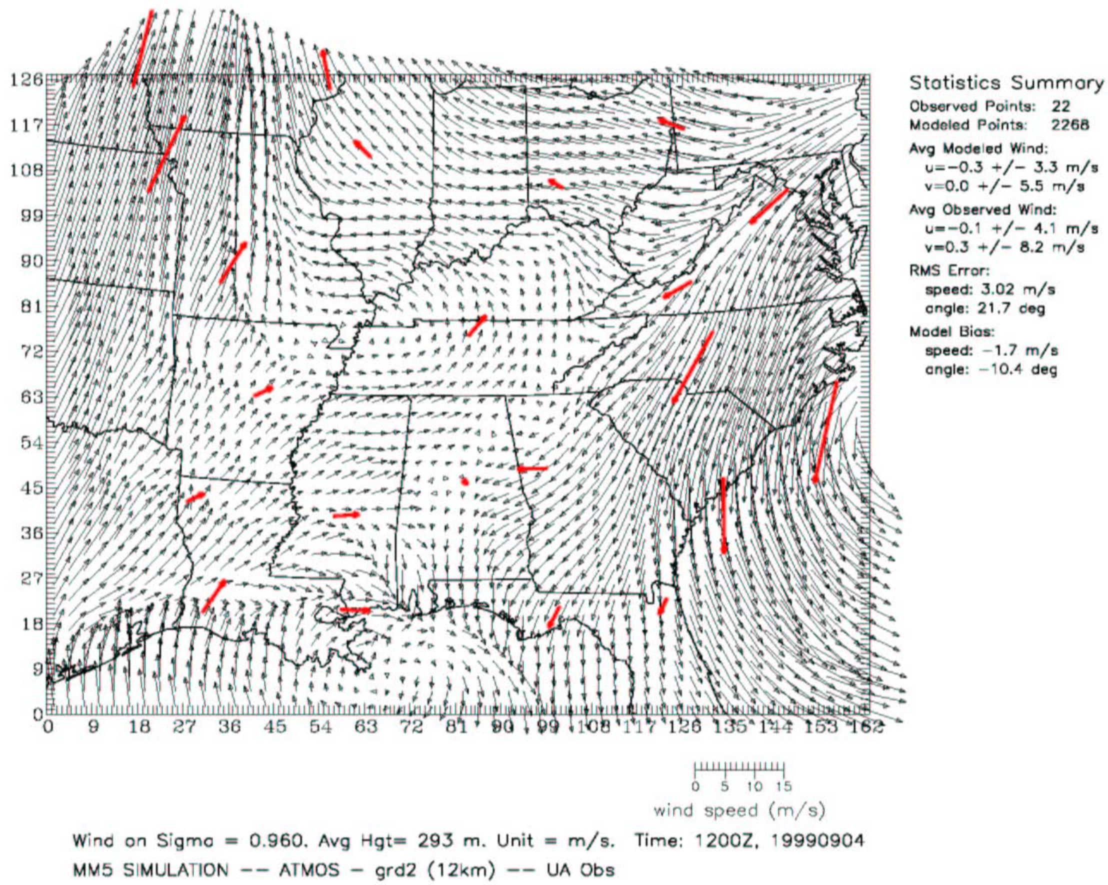


Figure 4-1h.
MM5-Derived 12-km Wind Field for 0700 EST on 5 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

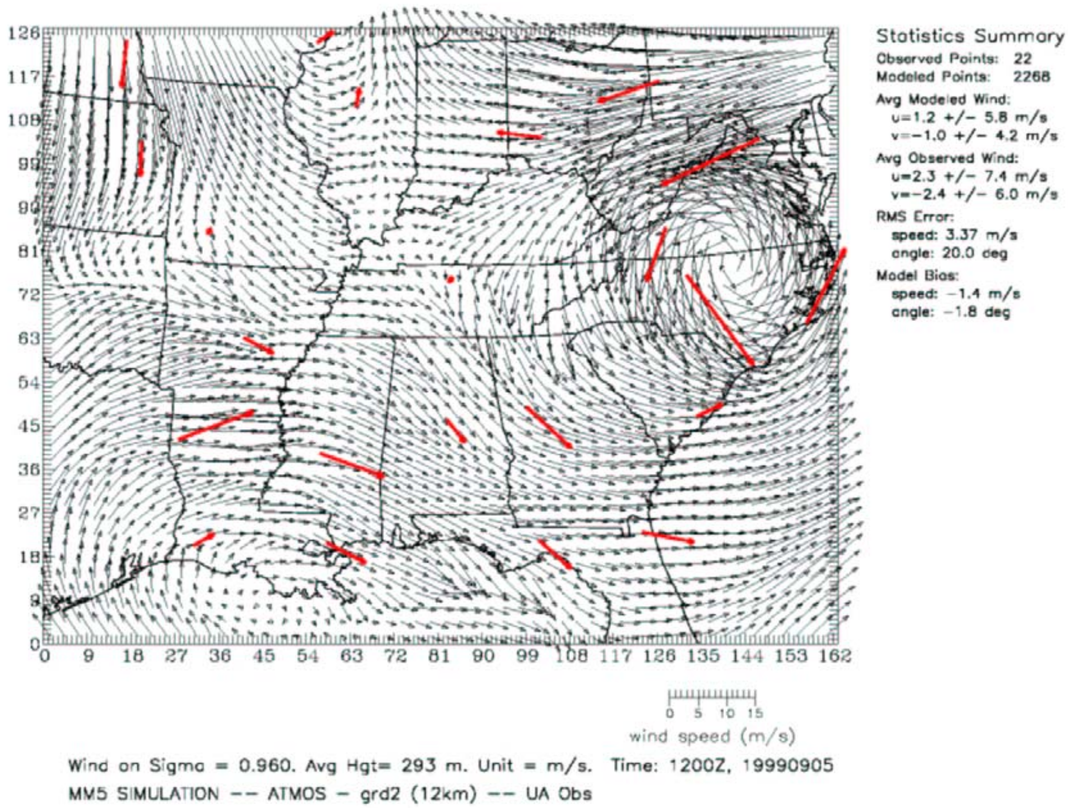


Figure 4-1i.
MM5-Derived 12-km Wind Field for 0700 EST on 6 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

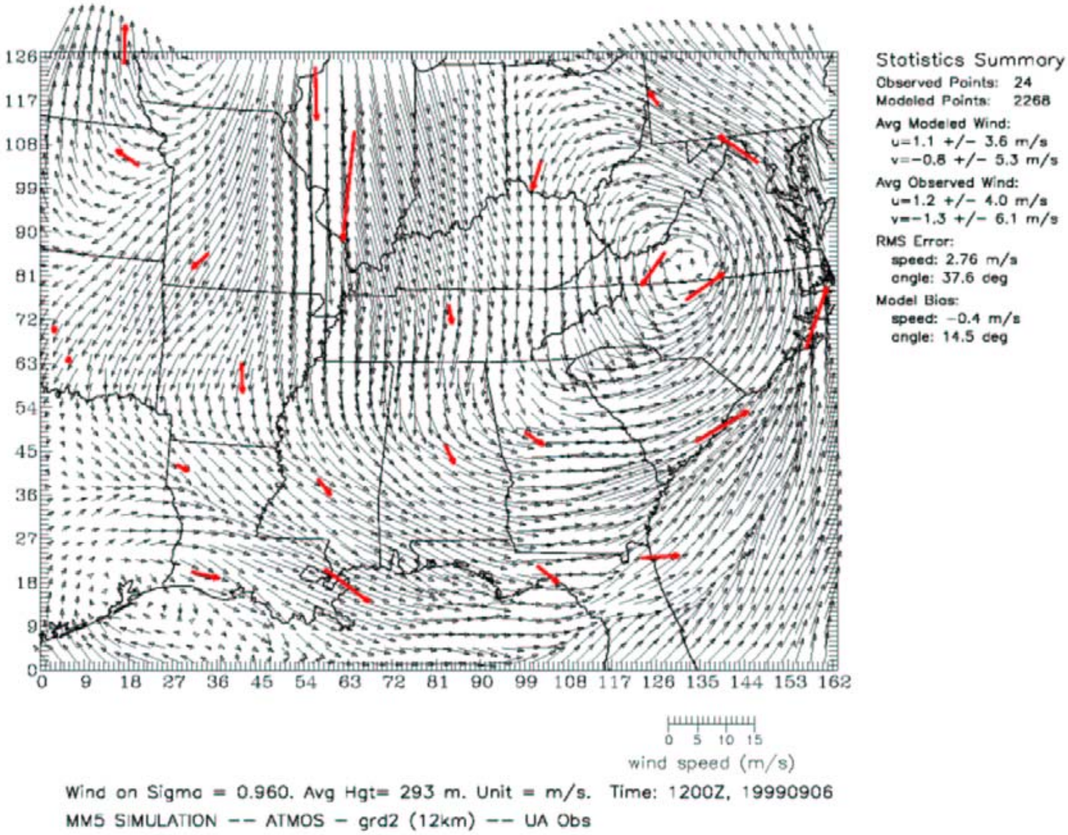


Figure 4-1j.
MM5-Derived 12-km Wind Field for 0700 EST on 7 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

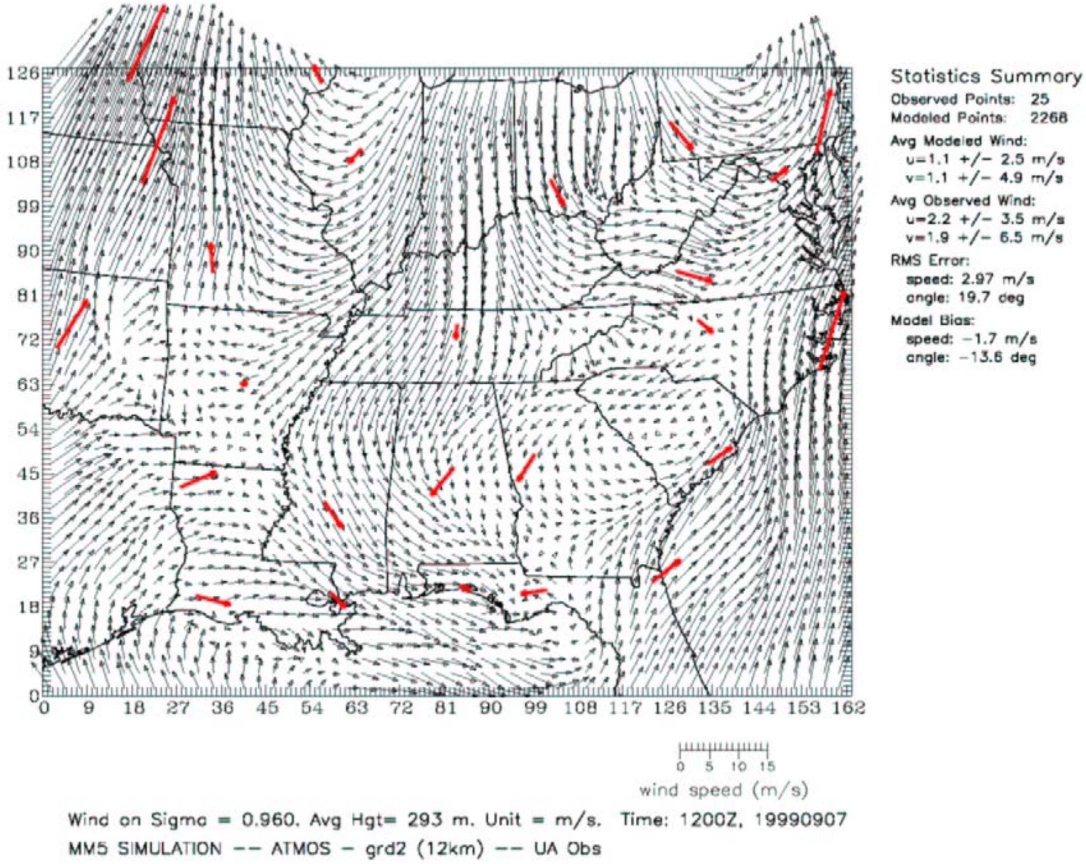


Figure 4-1k.
MM5-Derived 12-km Wind Field for 0700 EST on 8 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

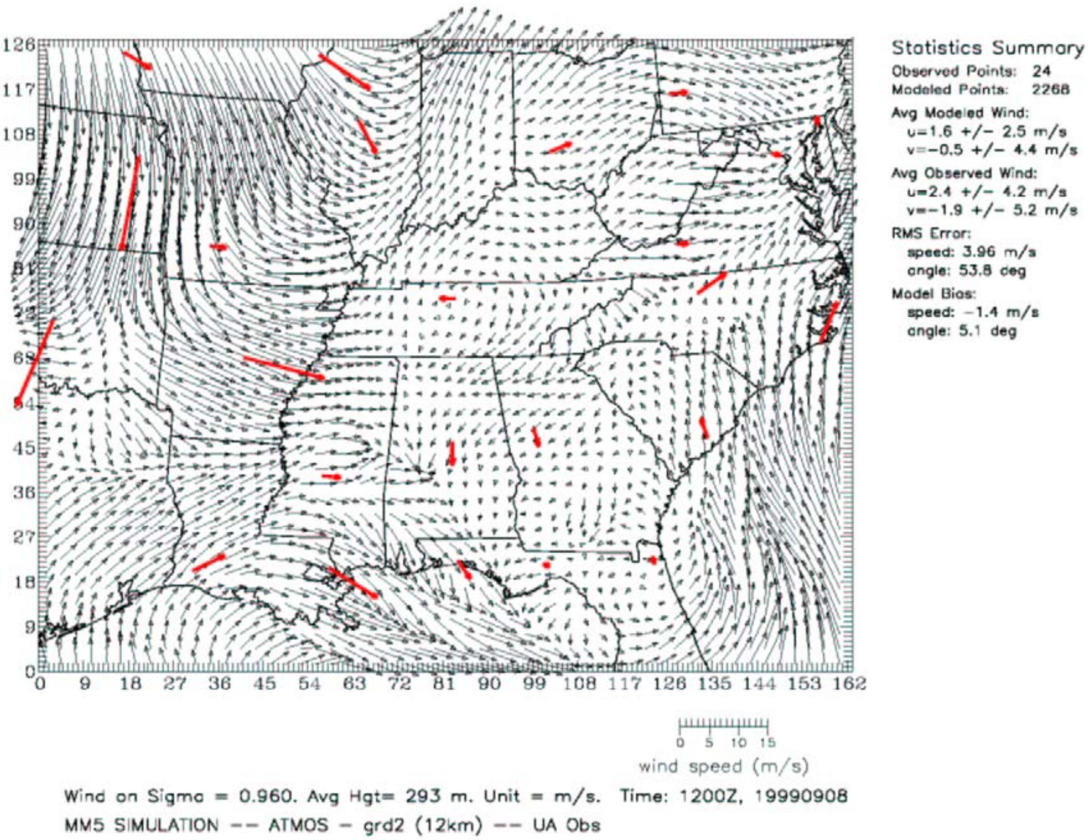


Figure 4-1l.
MM5-Derived 12-km Wind Field for 0700 EST on 9 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

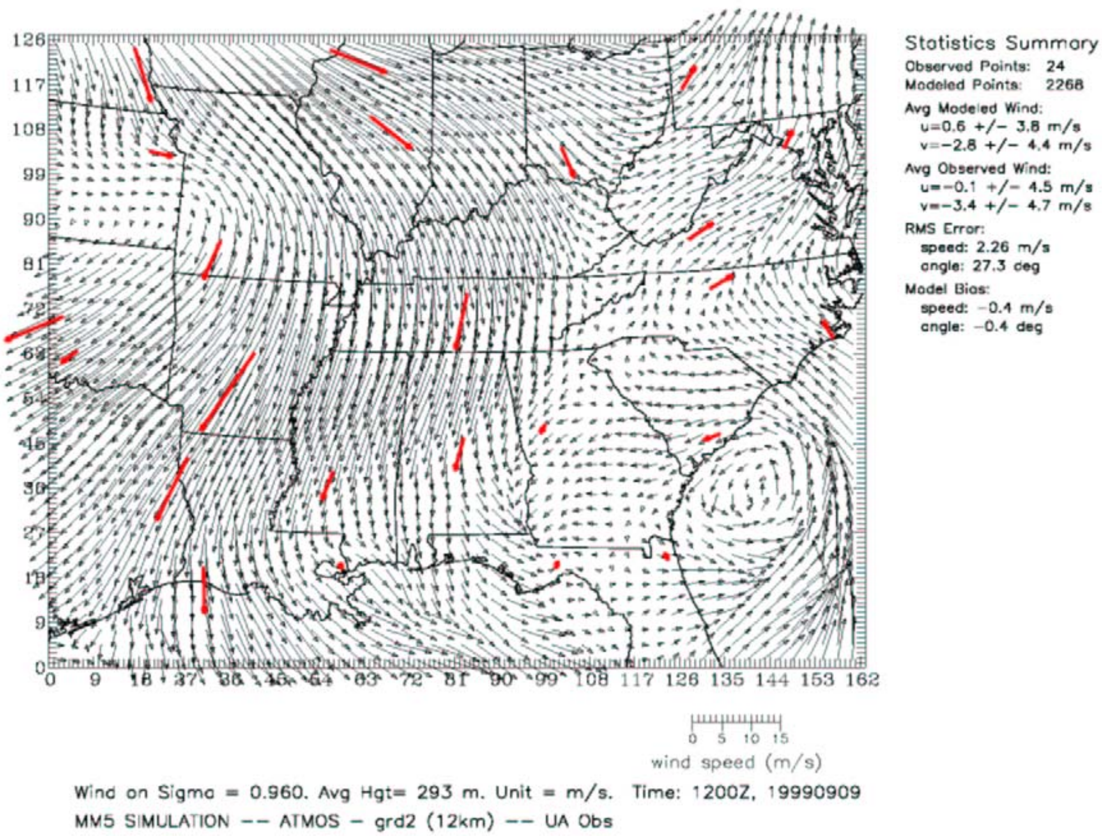


Figure 4-2.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga for 29 August to 9 September 1999

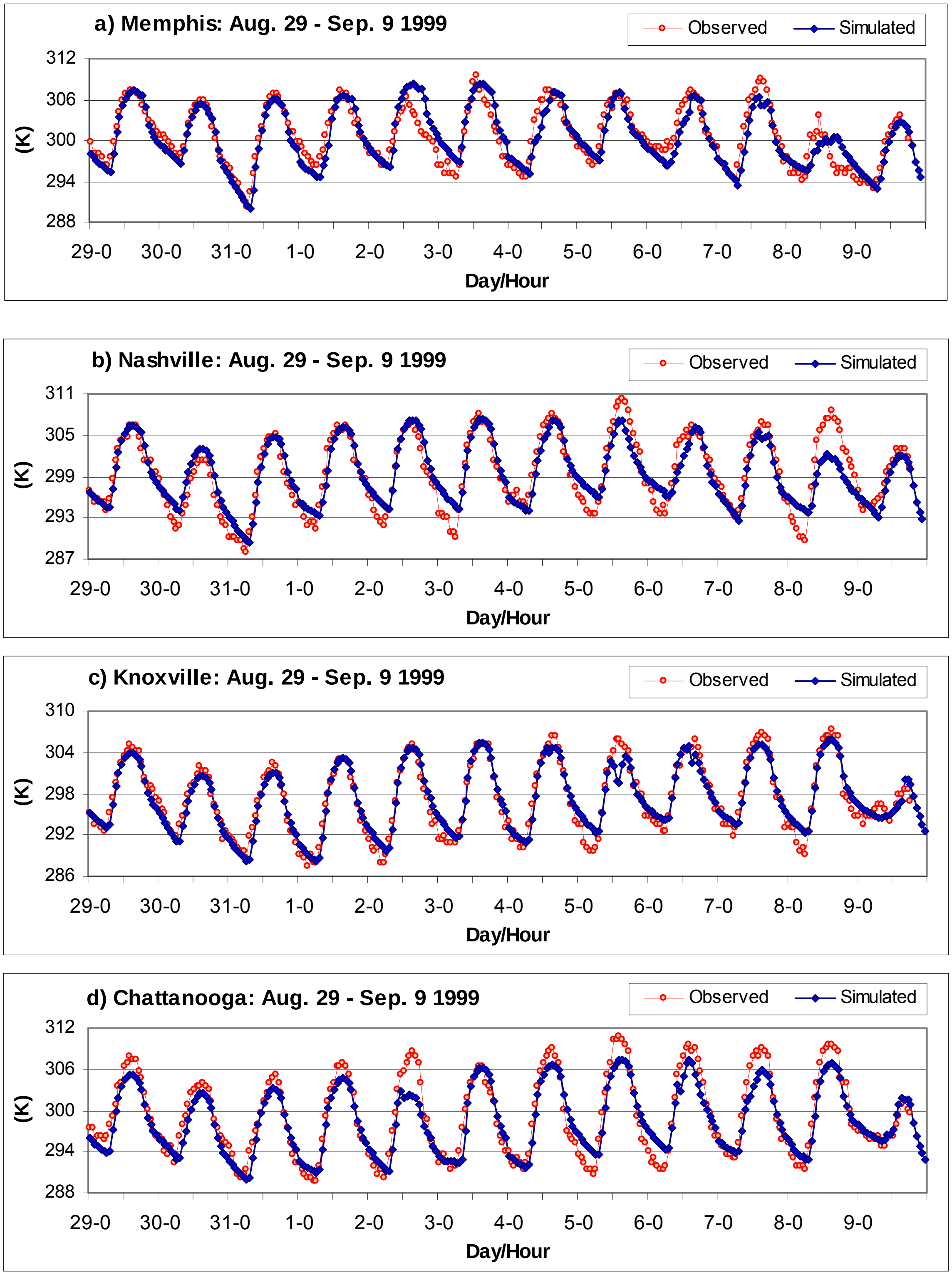
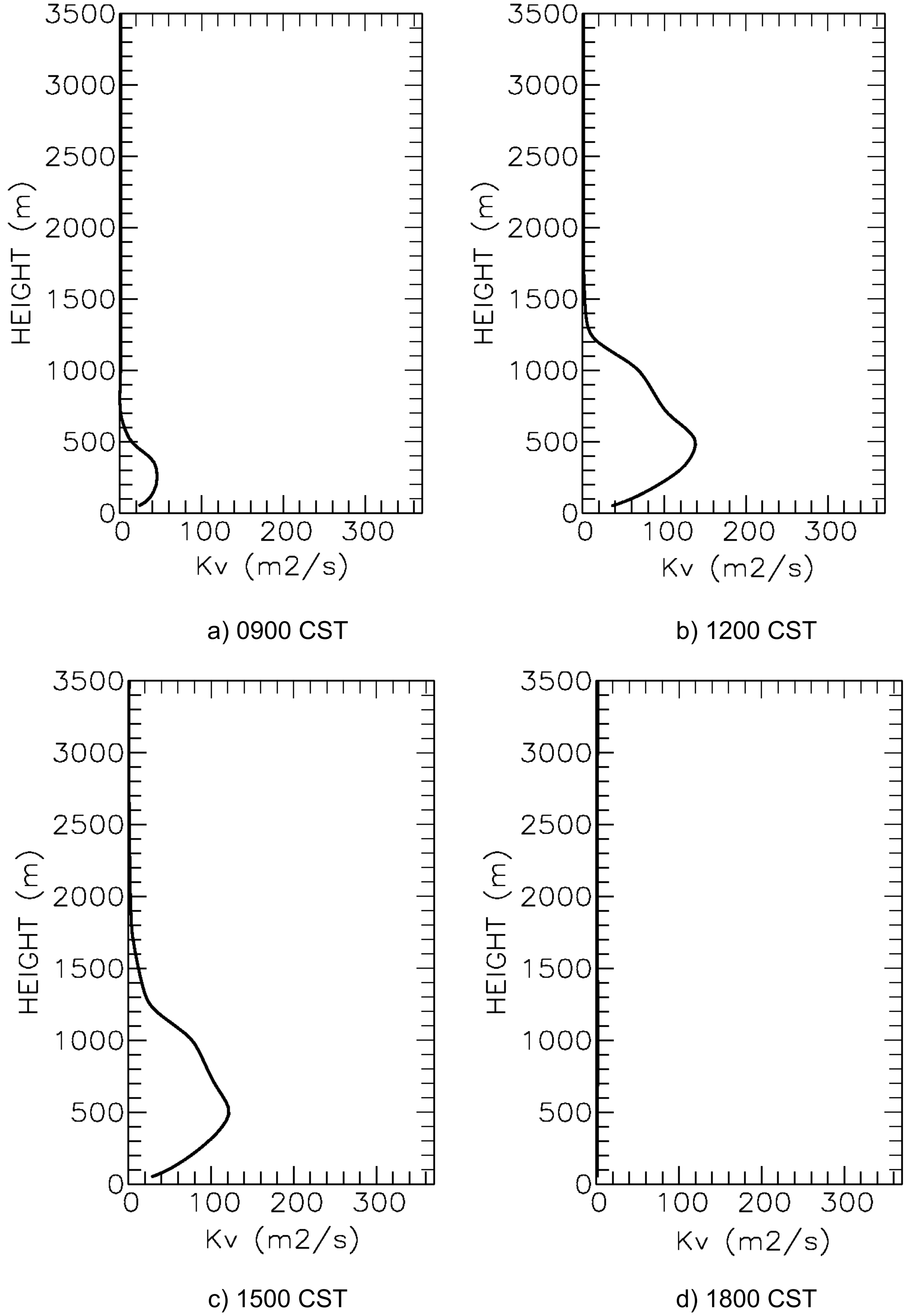


Figure 4-3.
K_v Profiles for Nashville, TN on 31 August 1999



a) 0900 CST

b) 1200 CST

c) 1500 CST

d) 1800 CST

Figure 4-4a.
MM5-Derived 12-km Wind Field for 0700 EST on 16 June 2001
at Approximately 300 m agl.

Observations are overplotted in bold

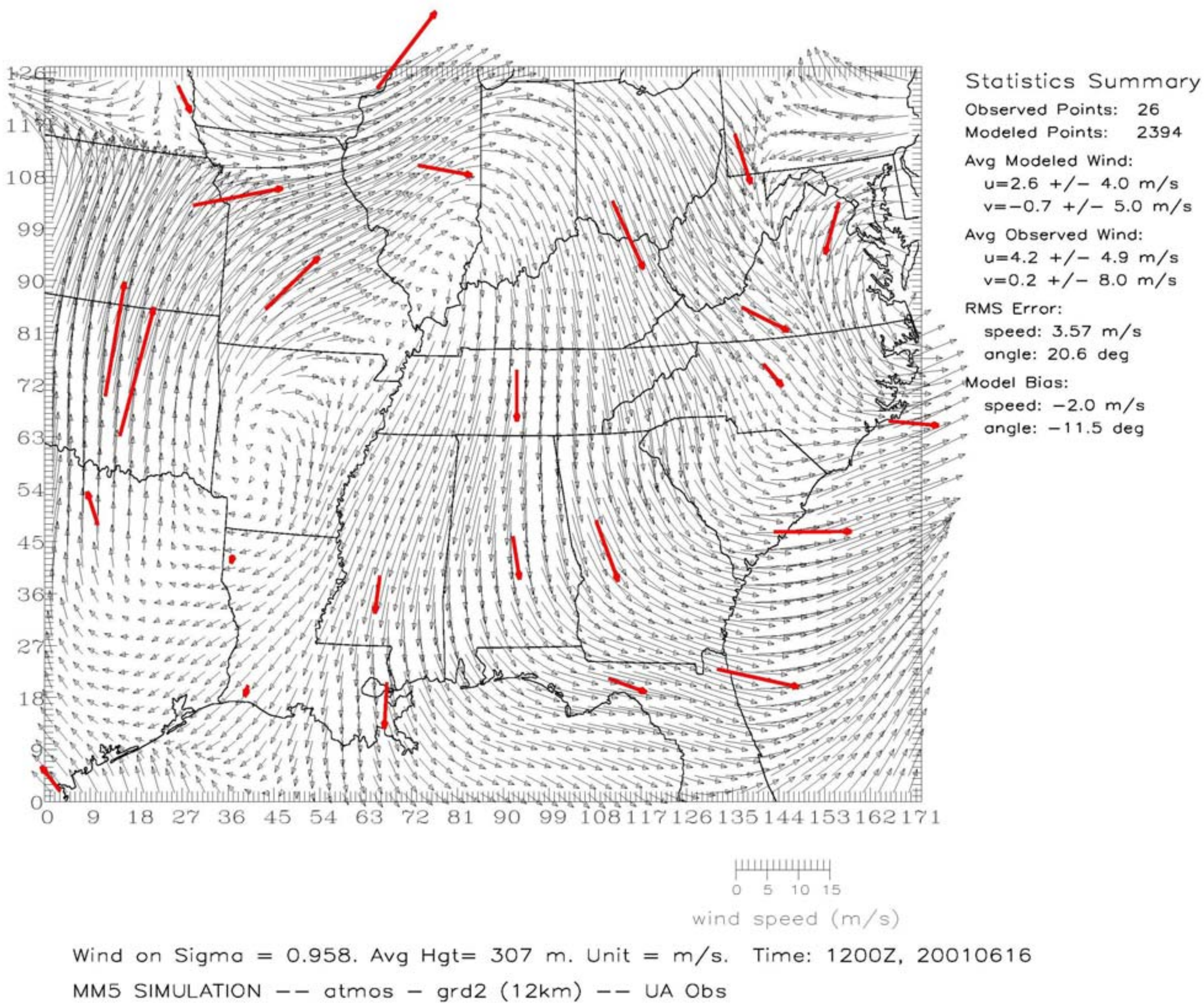


Figure 4-4b.
MM5-derived 12-km wind field for 0700 EST on 17 June 2001
at 300 m agl.

Observations are overplotted in bold.

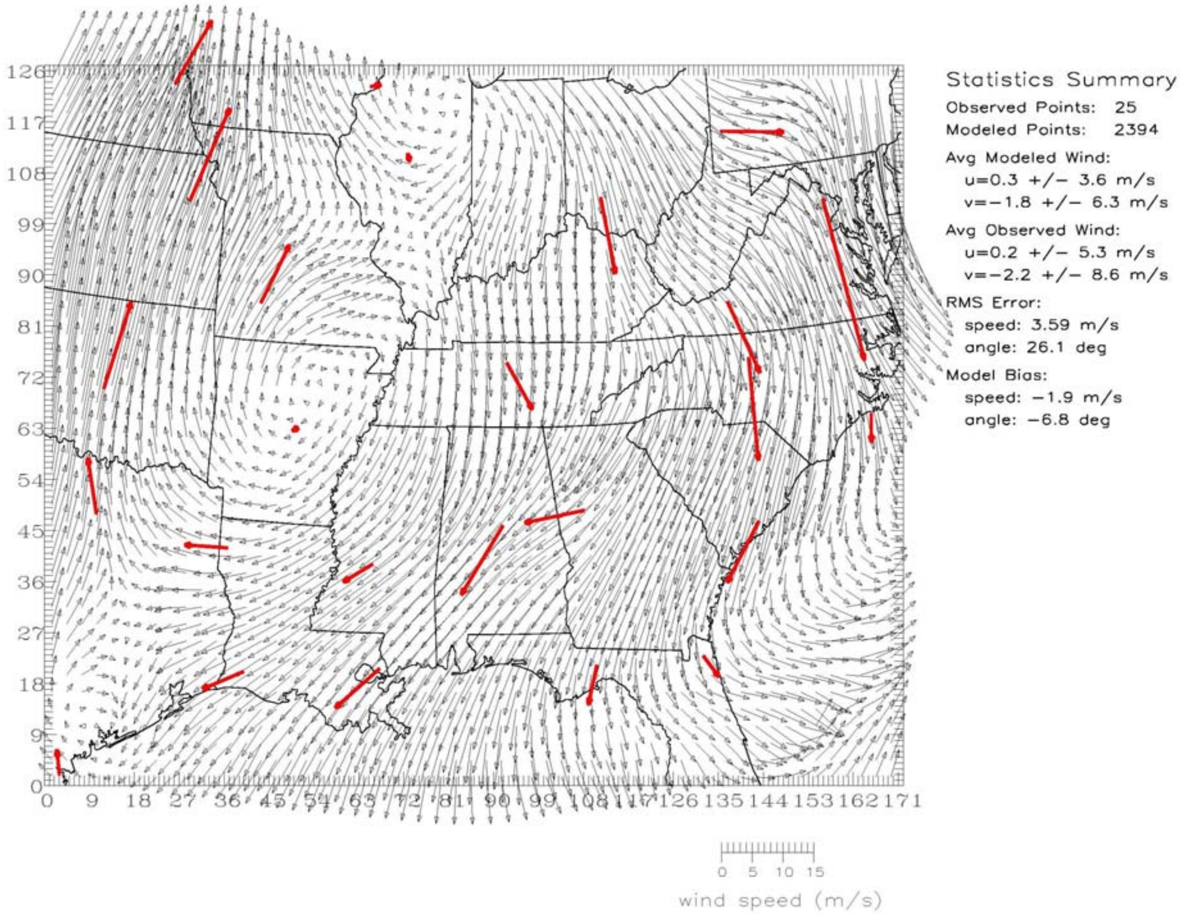


Figure 4-4c.
MM5-derived 12-km wind field for 0700 EST on 18 June 2001 at 300 m agl.

Observations are overplotted in bold.

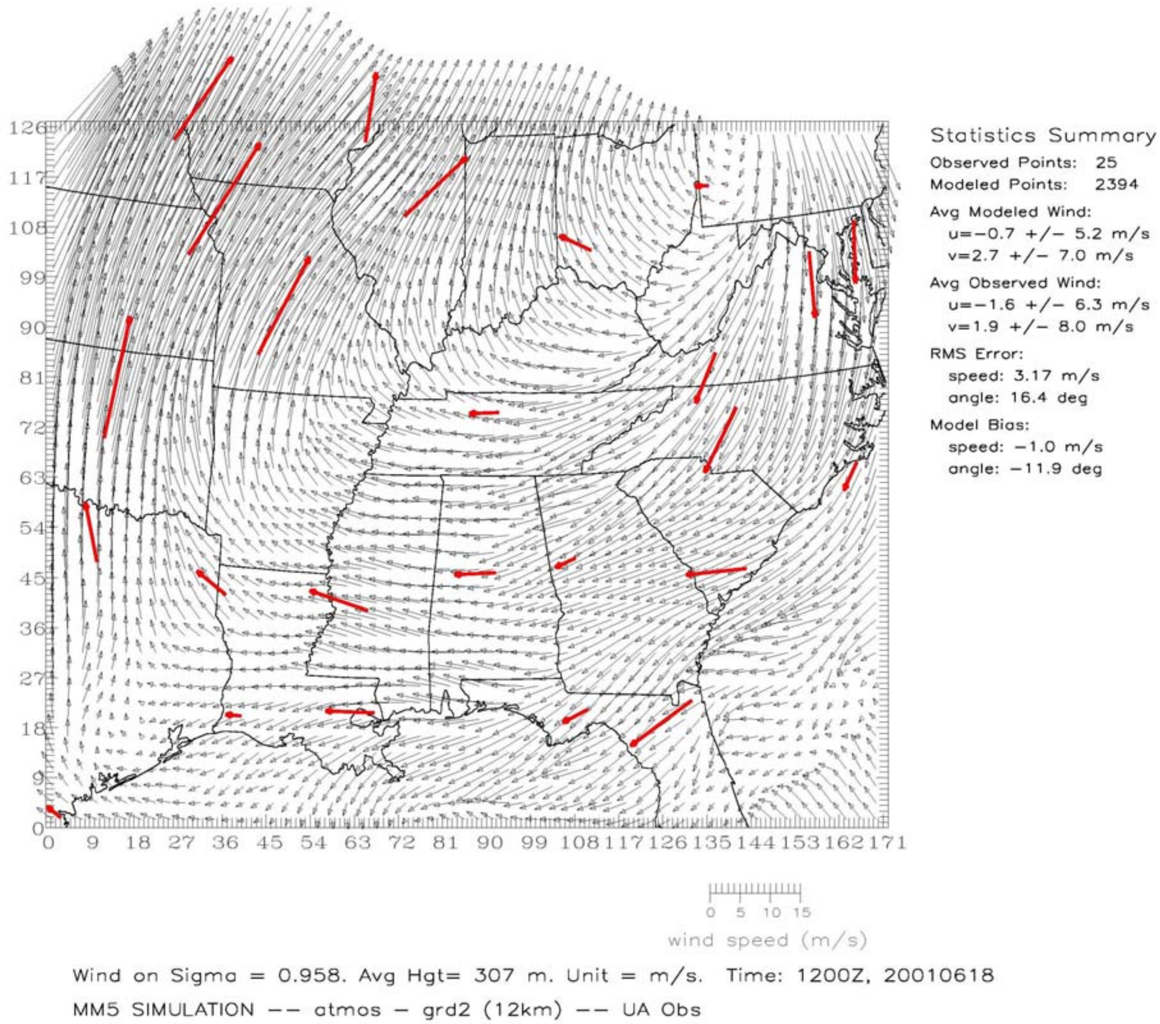


Figure 4-4d.
MM5-derived 12-km Wind Field for 0700 EST on 19 June 2001 at 300 m agl.

Observations are overplotted in bold.

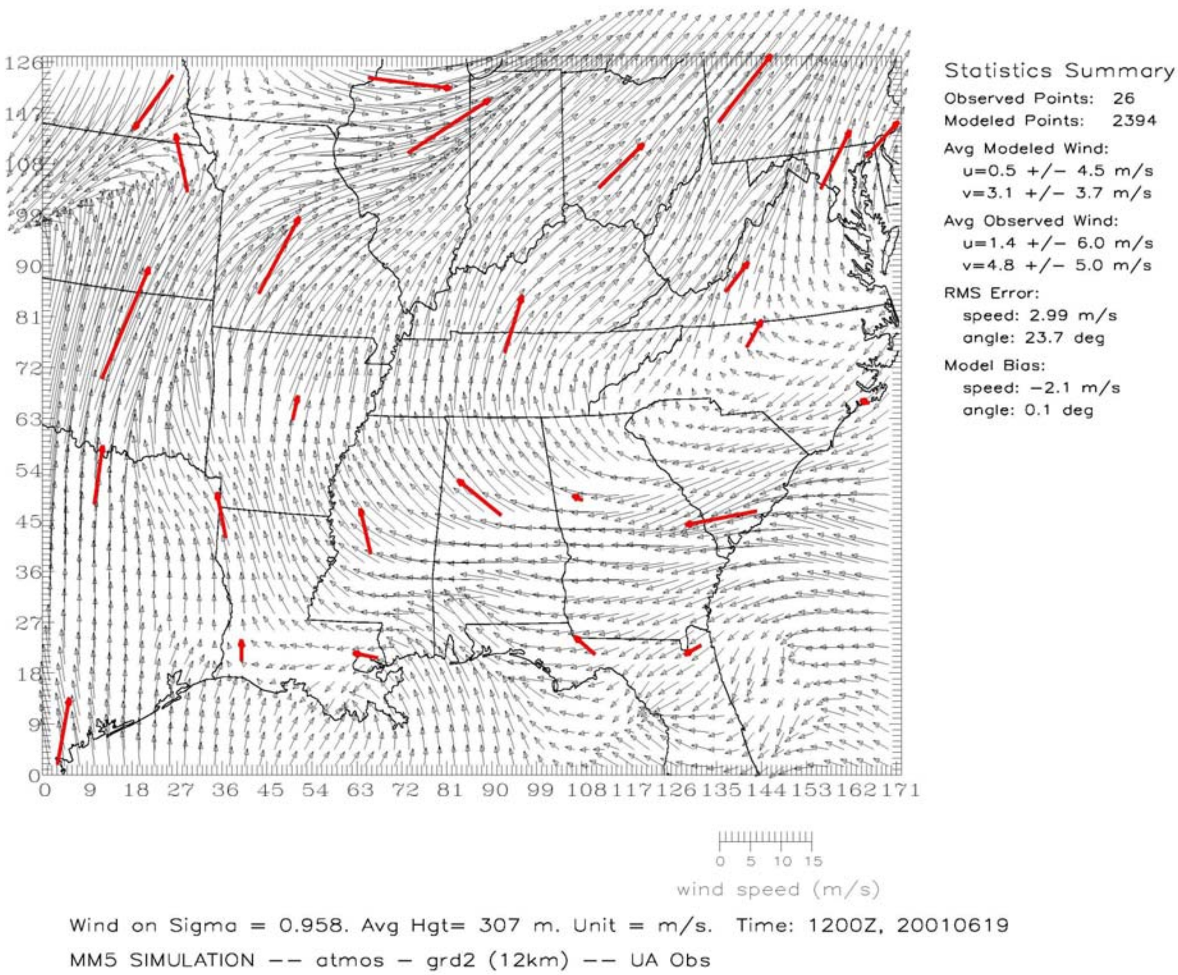


Figure 4-4e.
MM5-derived 12-km wind field for 0700 EST on 20 June 2001
at 300 m agl.

Observations are overplotted in bold.

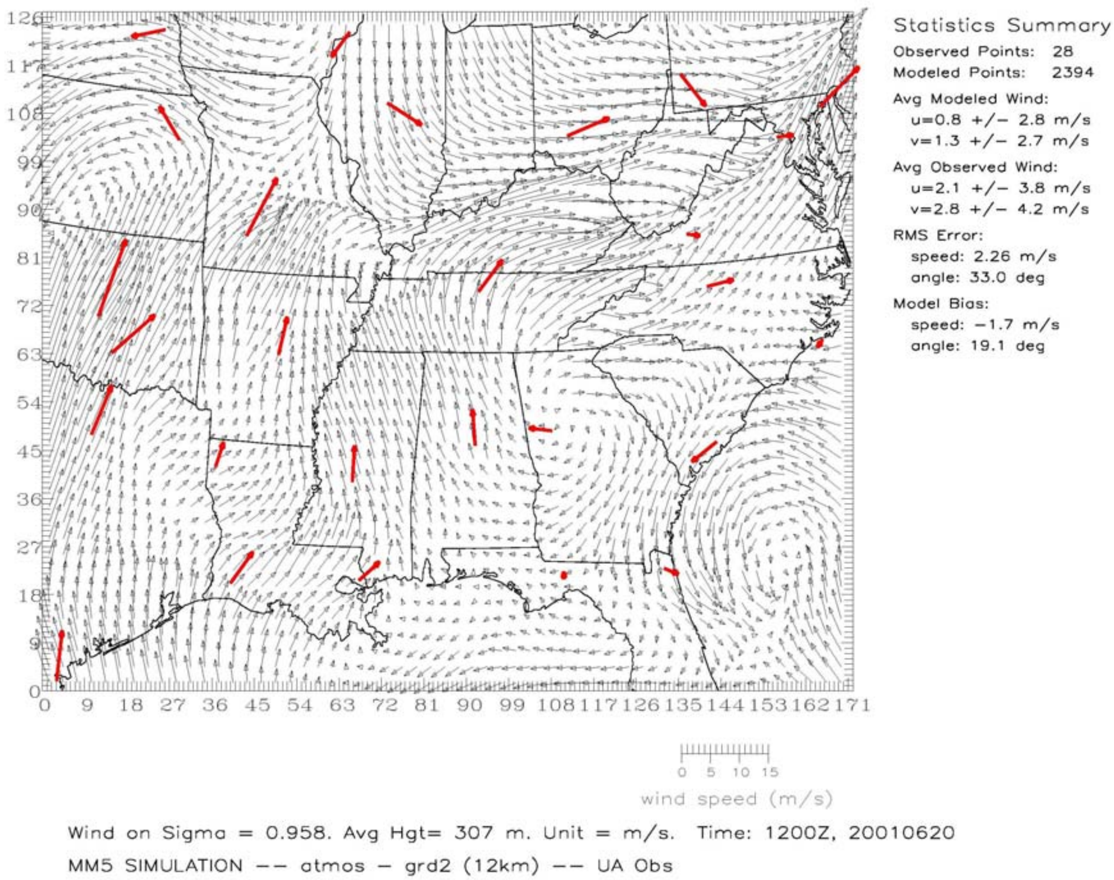


**Figure 4-4f.
MM5-derived 12-km wind field for 0700 EST on 21 June 2001
at 300 m agl.**

Observations are overplotted in bold.

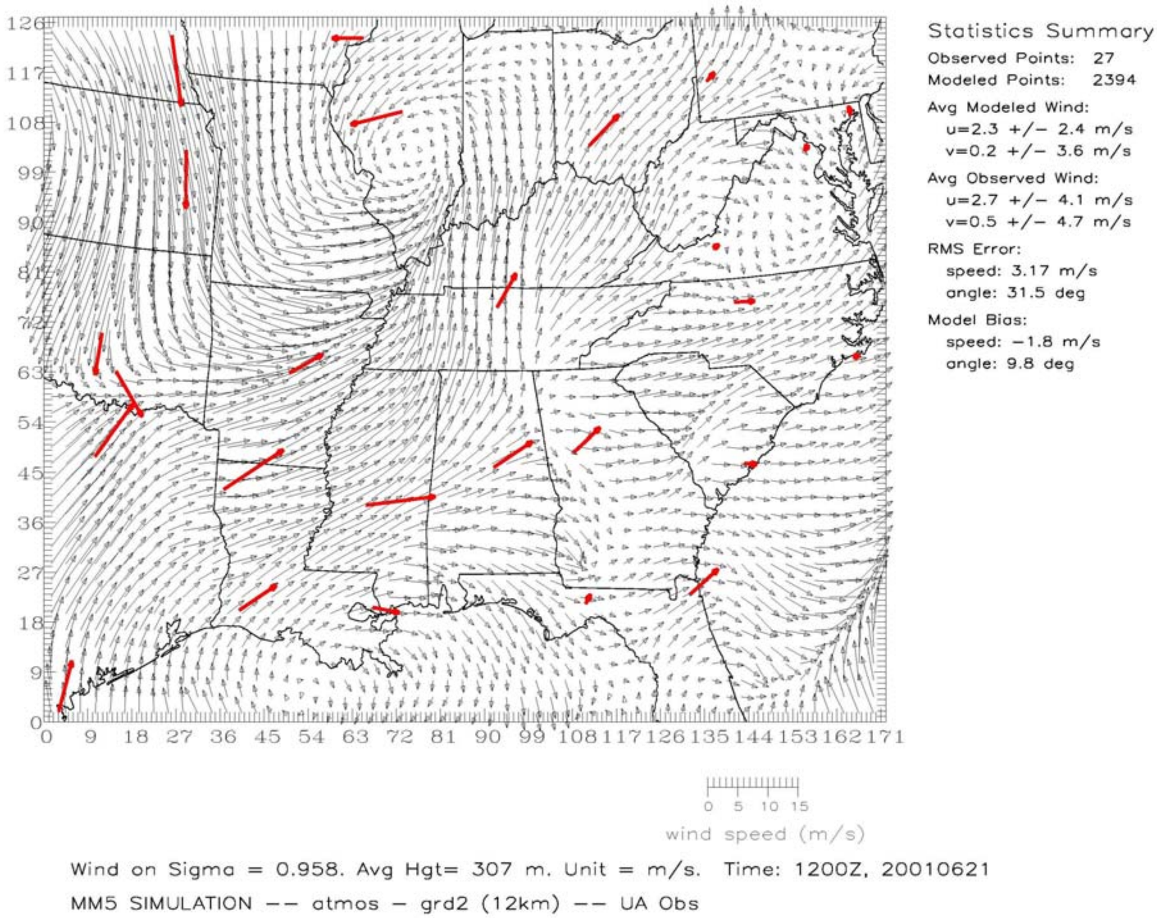


Figure 4-4g.
MM5-derived 12-km wind field for 0700 EST on 22 June 2001
at 300 m agl.

Observations are overplotted in bold.

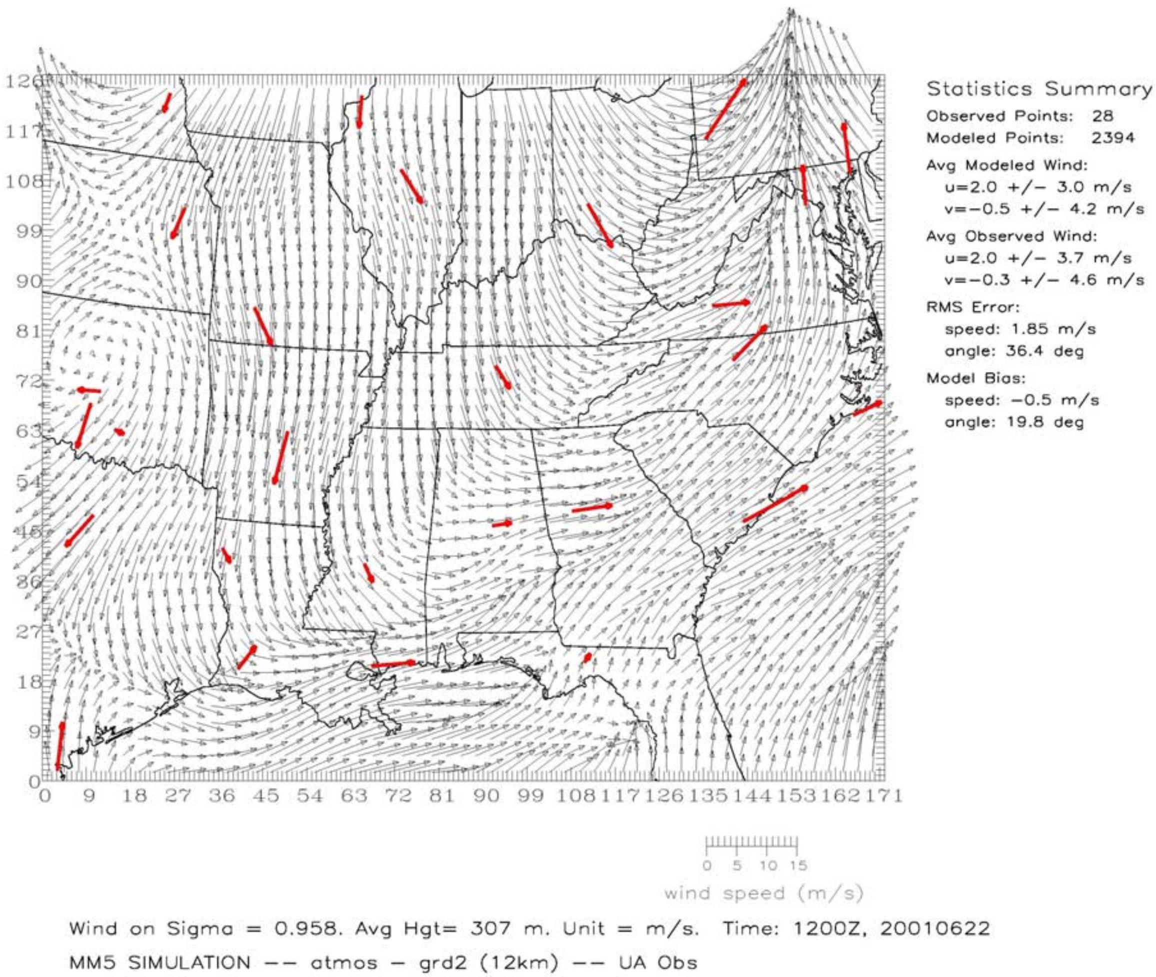


Figure 4-5.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga for 16–22 June 2001

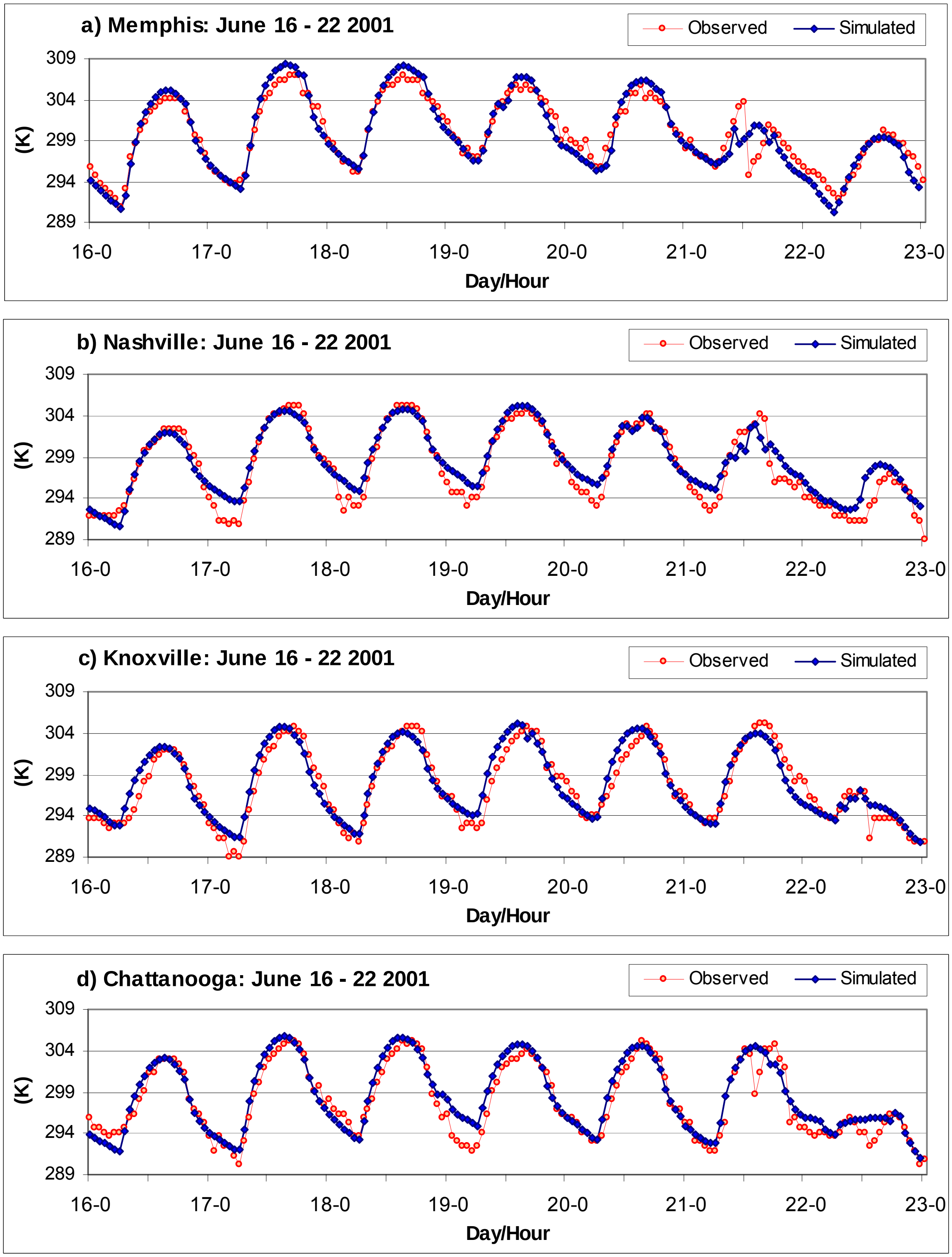


Figure 4-6a.
MM5-Derived 12-km Wind Field for 0700 EST on 4 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold

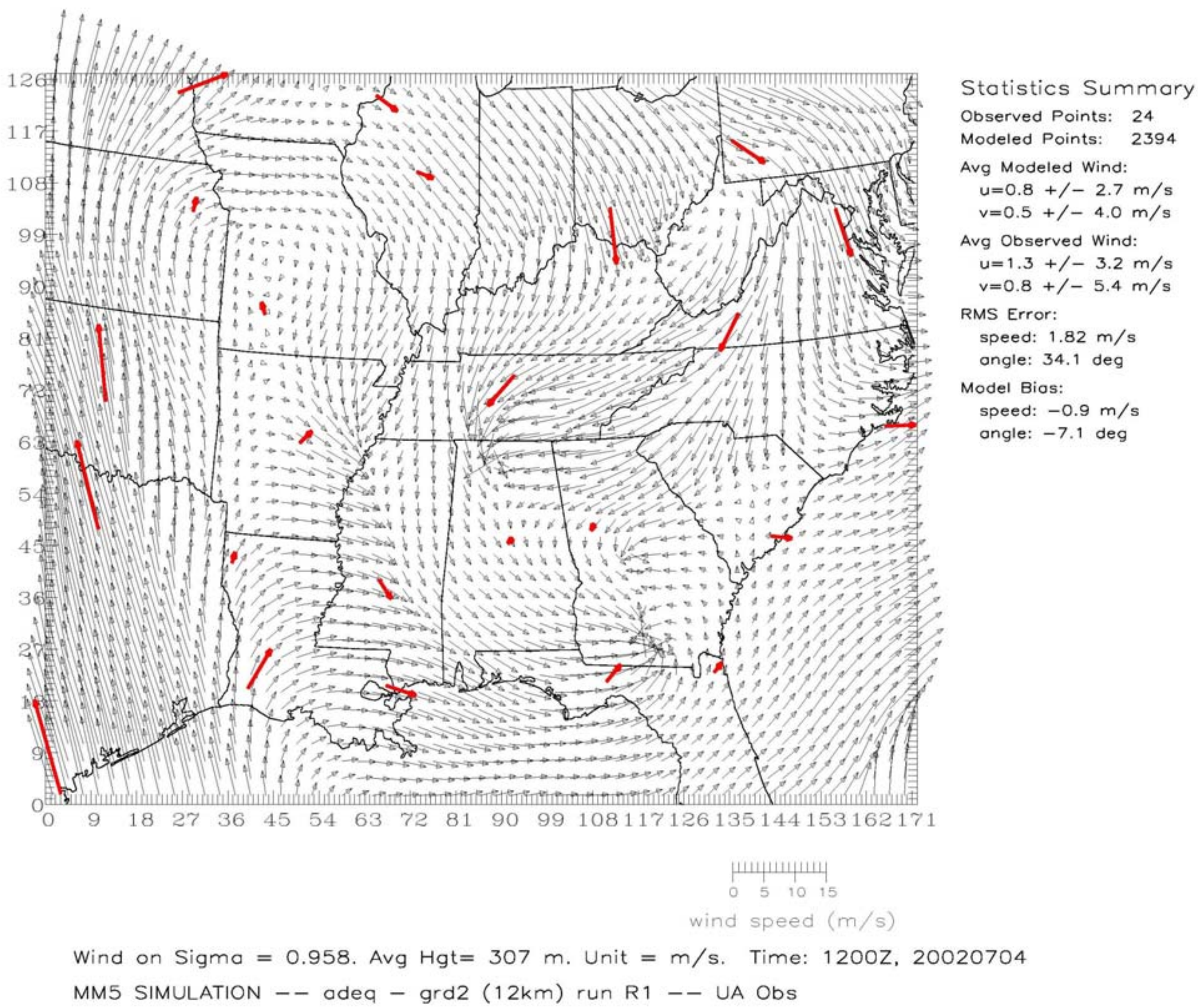


Figure 4-6b.
MM5-derived 12-km wind field for 0700 EST on 5 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

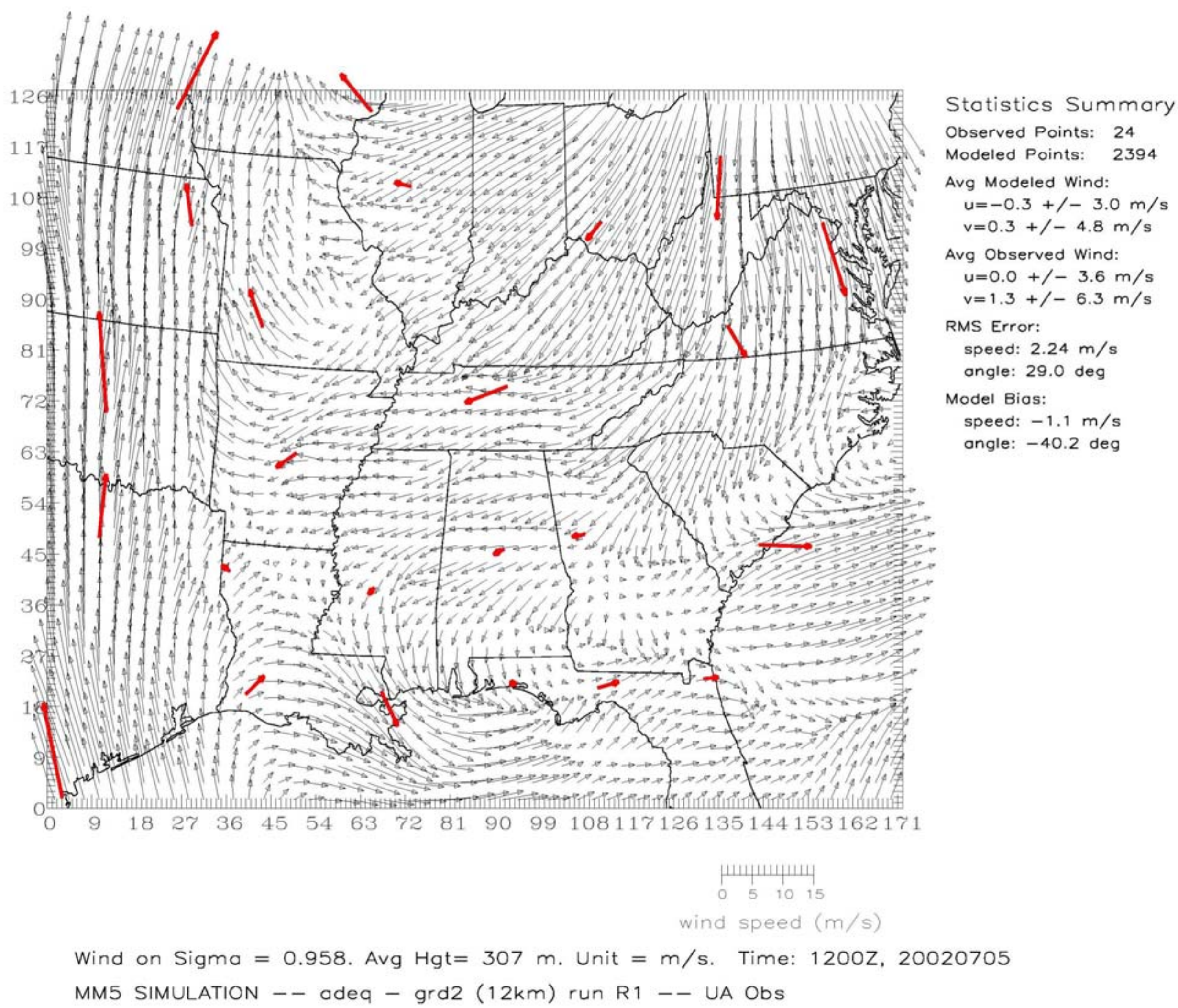


Figure 4-6c.
MM5-derived 12-km wind field for 0700 EST on 6 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

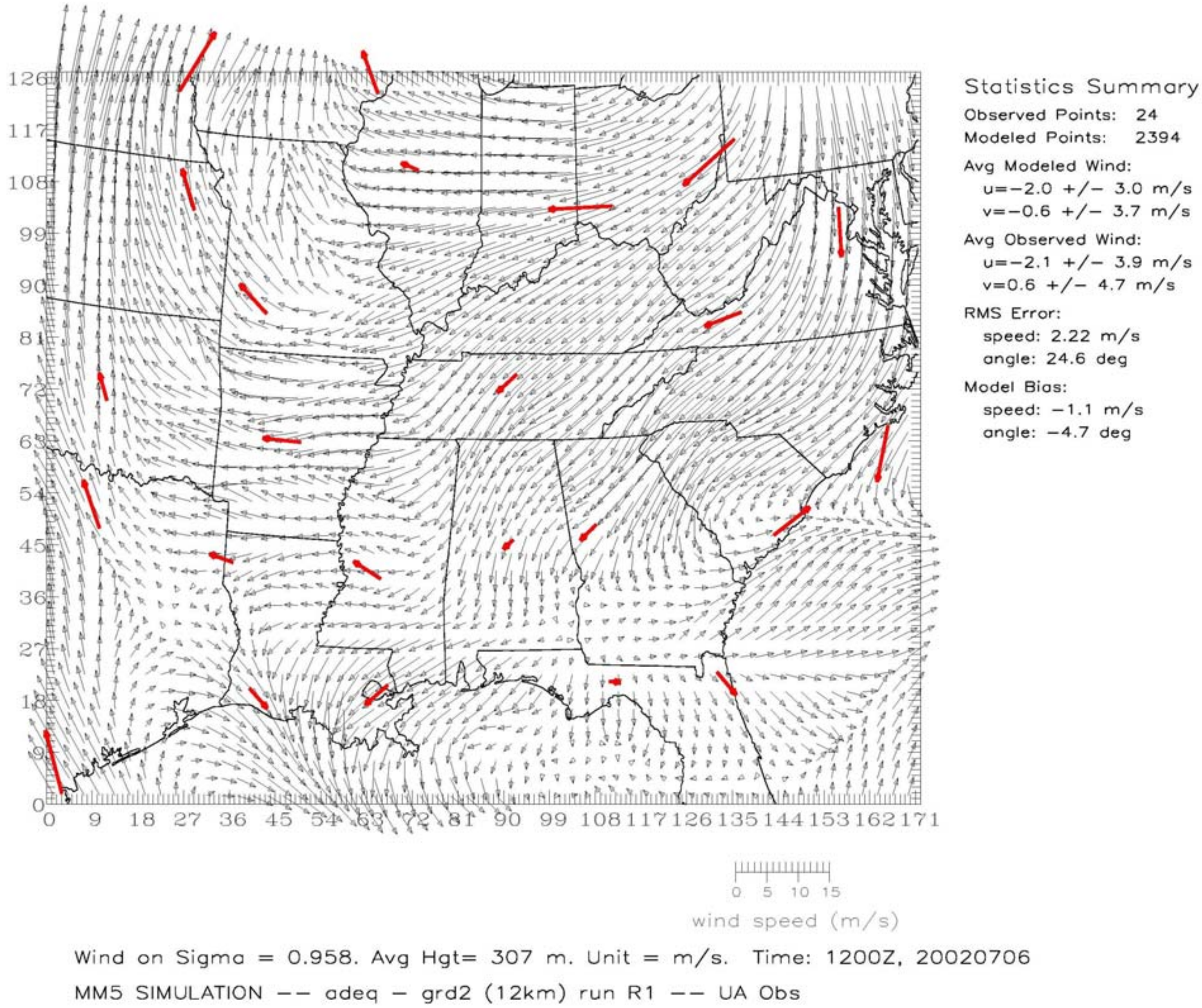


Figure 4-6d.
MM5-derived 12-km Wind Field for 0700 EST on 7 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

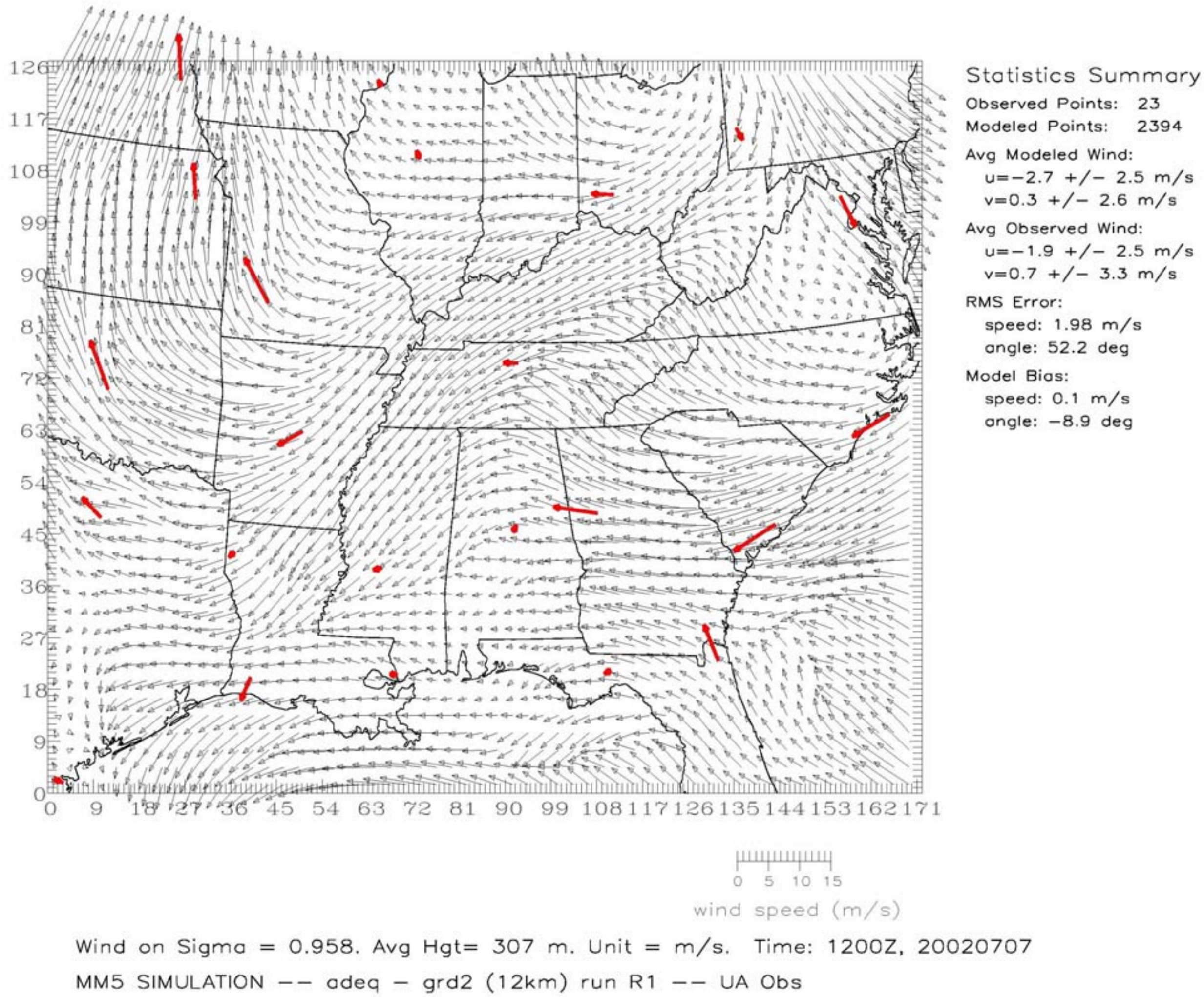


Figure 4-6e.
MM5-derived 12-km Wind Field for 0700 EST on 8 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

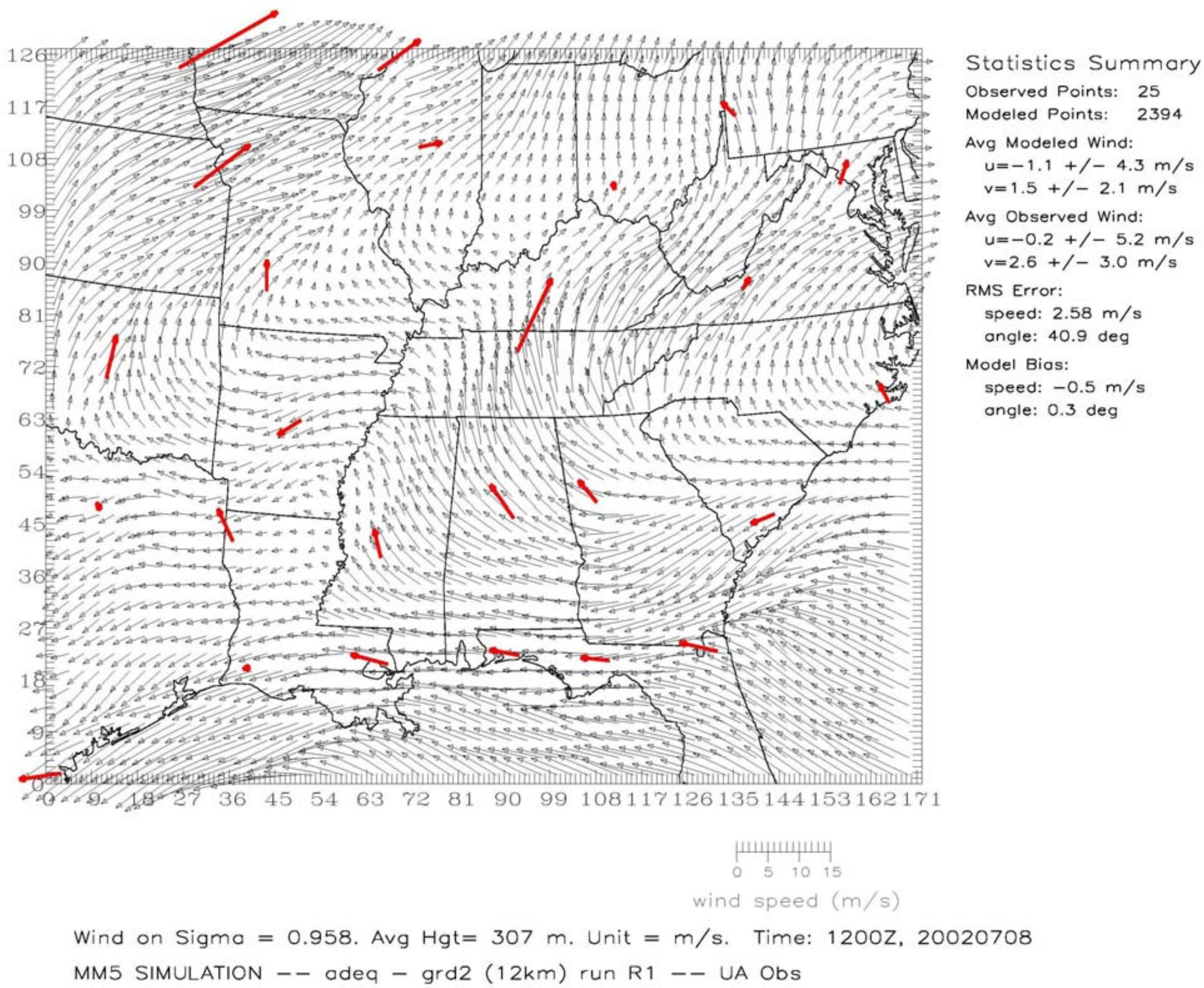


Figure 4-6f.
MM5-derived 12-km Wind Field for 0700 EST on 9 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

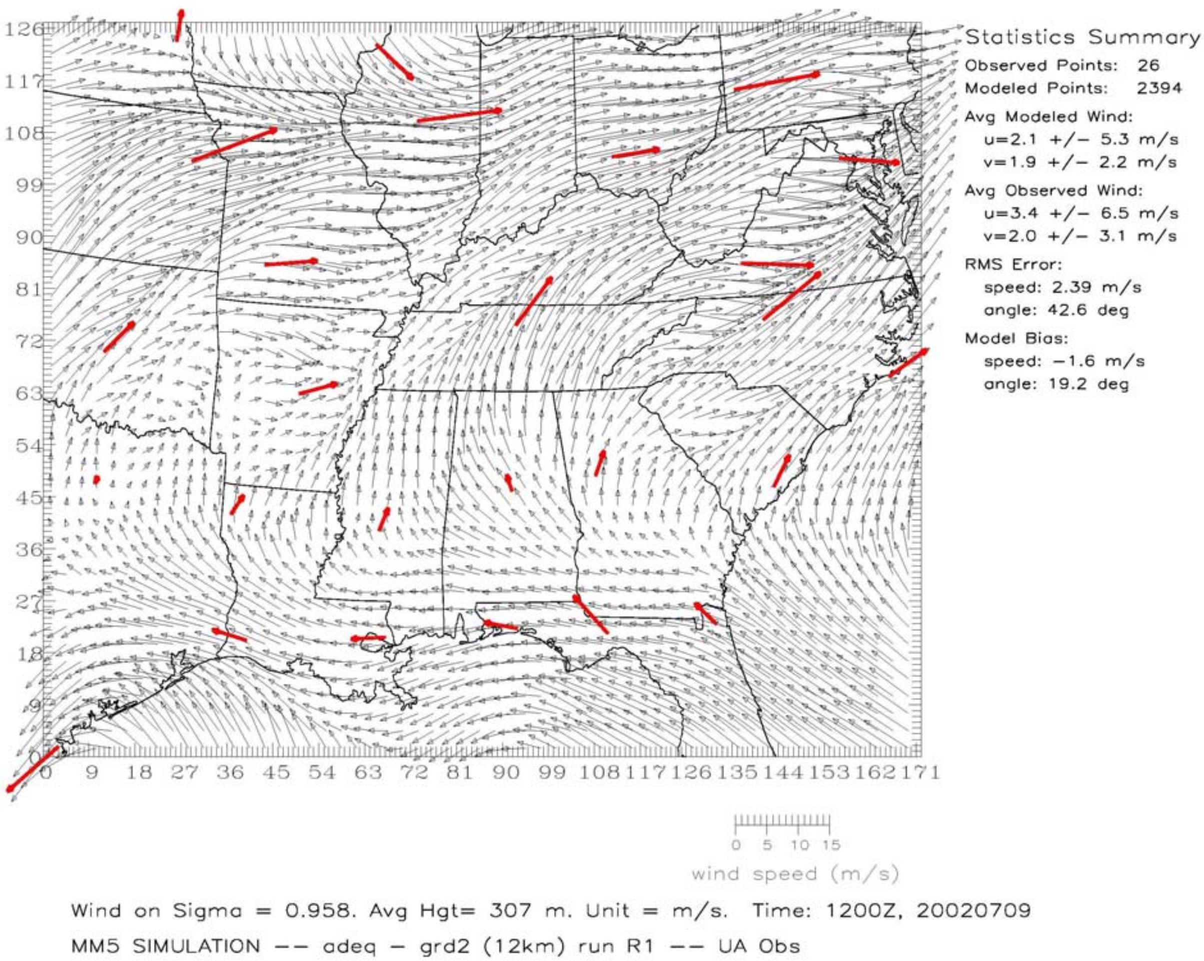


Figure 4-6g.
MM5-derived 12-km Wind Field for 0700 EST on 10 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

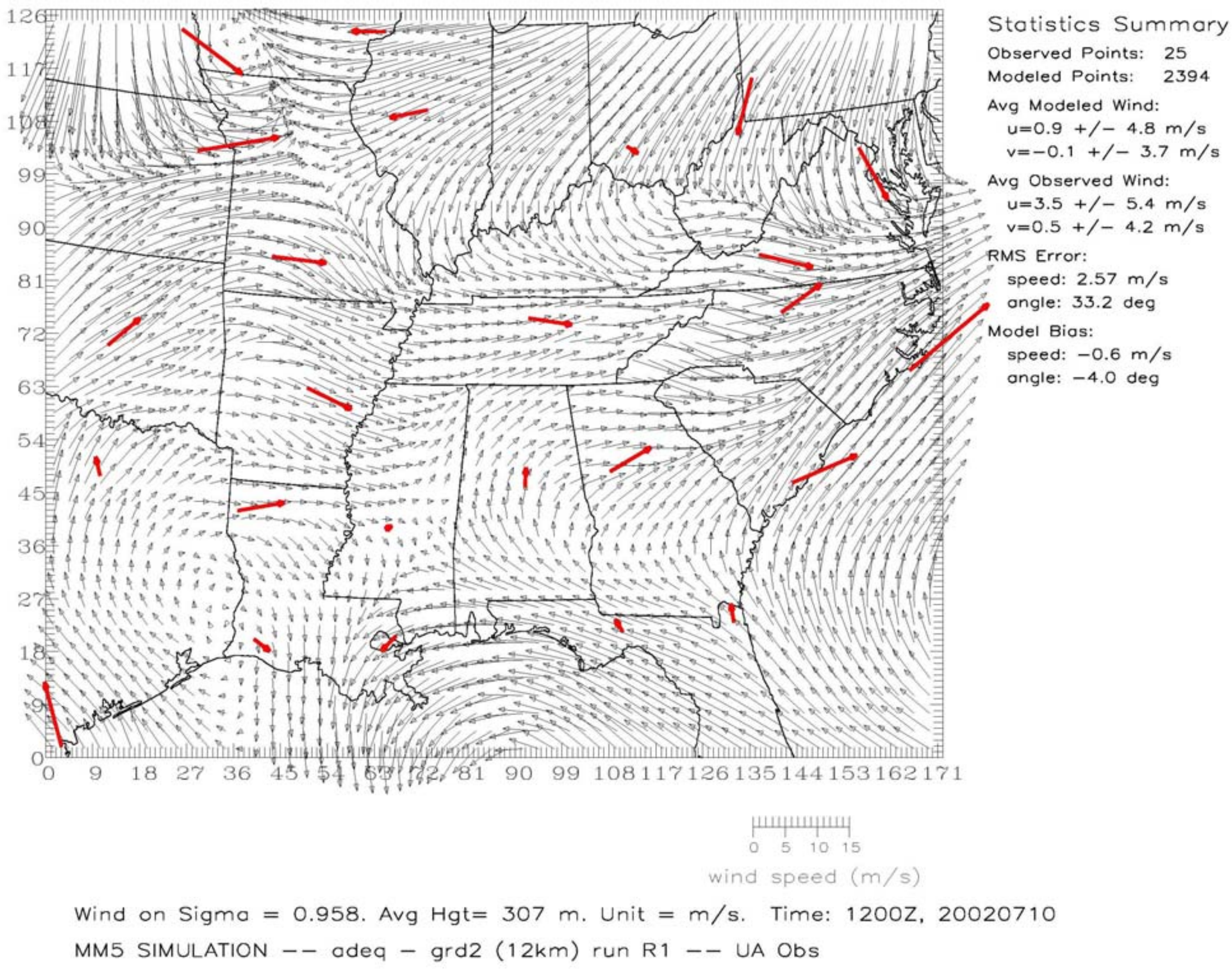
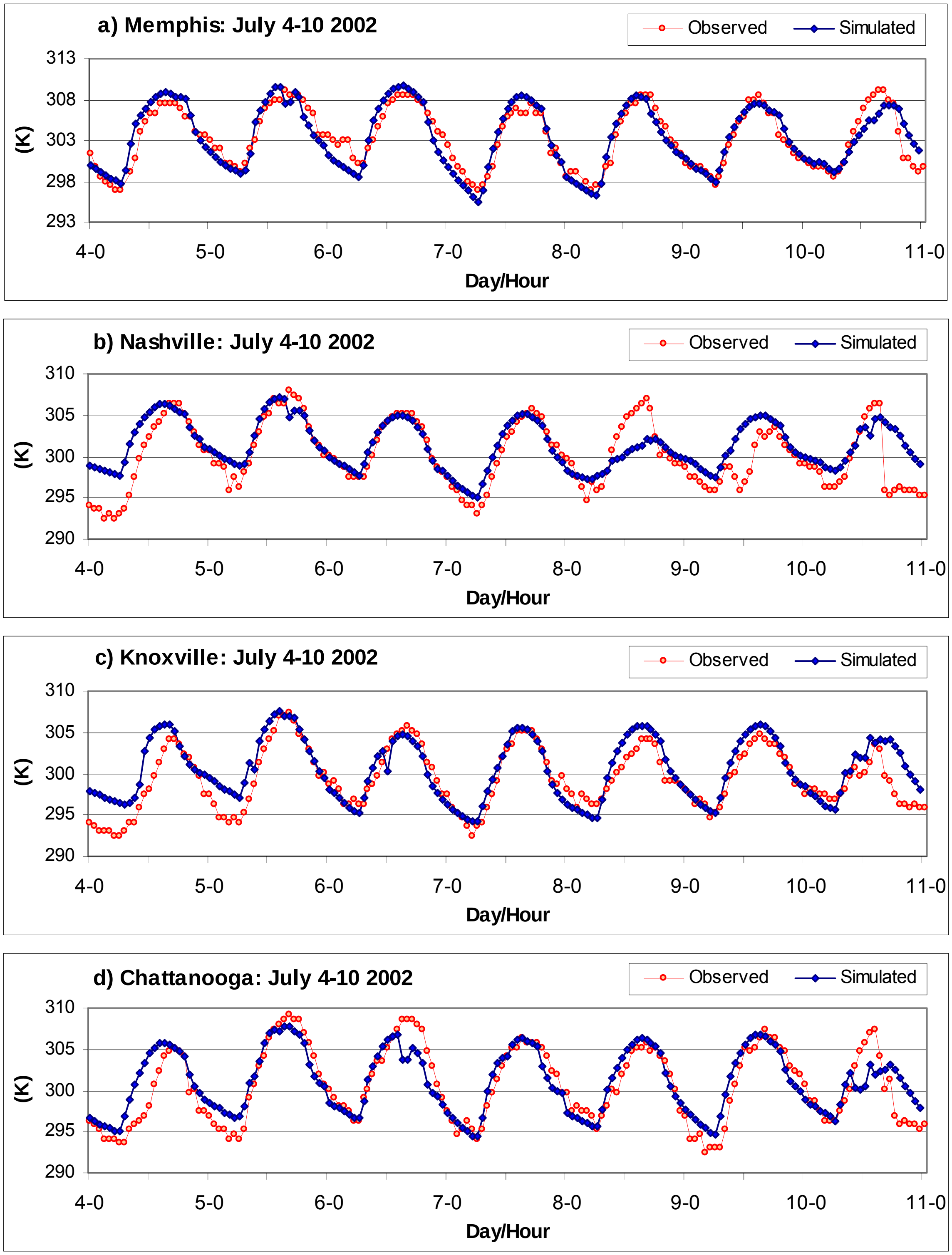


Figure 4-7.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga for 04–10 July 2002



5. Air Quality, Land-Use, and Chemistry Input Preparation

The UAM-V modeling system requires information on pollutant concentrations throughout the domain at the first hour of the first day of the simulation, and along the lateral and top boundaries of the domain for each hour of the simulation days. It also requires land-use data, albedo and ozone column values, photolysis rates, and chemical reaction rates. The UAM-V model obtains this information from input files that will be described in this section.

All figures are included following the text in this section.

Air Quality Related Inputs

Three UAM-V air quality input files define the initial and boundary pollutant concentrations for each of the UAM-V state species. The initial conditions file specifies the initial concentration for each species at the initial time of the simulation. The boundary conditions file specifies the concentration for each species along the lateral boundaries of the modeling domain for each hour of the simulation period. The top concentration files contain similar values for the species along the top boundary of the modeling domain for each simulation day.

Initial Conditions

For the ATMOS modeling domain, initial condition inputs for each simulation period were prepared using observed pollutant concentration data from all available monitoring sites located within the modeling domain. The observed data consisting of measurements of ozone, NO, NO_2, and CO were obtained from the EPA Aerometric Information Retrieval System (AIRS). The first (hourly) measurement for the first day of the simulation period was used to specify the initial concentration for each species. If data for the first hour were missing, data for the second hour were used instead.

Observed data were interpolated to the lowest model layer of the modeling domain (Grid 1) using the standard UAM-V preprocessor program. This program relies on bilinear interpolation to estimate values of each species for each grid cell of the modeling domain. The surface layer values were extended to the second layer of the model (which ranges from 50 to 100 m above ground). Above this layer, EPA default values for each pollutant species (EPA, 1991) were used for the initial conditions for most species. For NO_x and CO some lower values than the EPA default values were used. The initial values are 40 ppb for ozone, 1 ppb for NOx (0 ppb for NO and 1 ppb for NO_2), 25 ppb for hydrocarbons (divided among the lumped hydrocarbon species represented in the CB-V mechanism, using a consistent approach to that listed in EPA (1991)), and 200 ppb for CO. The initial value for ozone was later adjusted to 65 ppb based on the results of the “self-generating boundary conditions” technique that will be described later in this section.

Boundary Conditions

The nested-grid, regional-scale modeling domain was designed, in part, to reduce the effects of uncertainty in the boundary conditions on the simulation results for the area of interest. The idea is that if the boundaries are far away enough from the area of interest, the impact of the boundary conditions will be absorbed by activity within the domain before they reach the area of interest. Lateral boundary conditions are specified for the outermost domain (Grid 1). Top boundary conditions are specified for all domains in a single file. For this study, the lateral and top boundary concentrations for all pollutants were initially set equal to the values listed for the initial conditions. These were assumed to be representative of continental-scale background values.

The value for ozone in the boundary and top concentration files was then updated for each simulation day. Using self-generating ozone boundary condition technique, an average ozone concentration from the upper layer of the modeling domain is calculated for the last hour of each day and is used to specify the ozone boundary value (along the lateral and top boundaries) for each subsequent day. Following the first full simulation for each modeling episode period, the self-generated values of ozone were analyzed and the initial value of ozone of 40 ppb for the boundary conditions was increased to approximately 60 ppb (this varied by episode) based on the calculated value for the subsequent days and the general trend followed by the ozone value throughout the simulation. In this manner, regional-scale build-up and/or lowering of ozone concentrations are represented in the simulations. The ozone boundary conditions for each of the simulation periods remained around 60-65 ppb for the entire period.

Land-Use Inputs

UAM-V requires a gridded land-use file for the full domain and each of the sub-domains, in order to calculate deposition rates. The file was prepared using a 200-m resolution land-use database obtained from the U.S. Geological Survey (USGS). Each of the categories in the USGS land-use database was assigned to one of the eleven UAM-V land use categories: urban, agricultural, range, deciduous forest, coniferous forest (including wetlands), mixed forest, water, barren land, non-forest wetlands, mixed agricultural and range, and rocky (low shrubs). The UAM-V land-use categories along with the surface roughness and albedo values for each category are listed in Table 5-1.

Table 5-1.
Land-Use Categories Recognized by UAM-V.
Surface roughness and UV albedo values are given for each category.

Category	Land-Use Description	Surface Roughness (m)	Albedo
1	Urban	3.00	0.08
2	Agricultural	0.25	0.05
3	Range	0.05	0.05
4	Deciduous forest	1.00	0.05
5	Coniferous forest including wetland	1.00	0.05
6	Mixed forest	1.00	0.05
7	Water	0.0001	0.04
8	Barren land	0.002	0.08
9	No forest wetlands	0.15	0.05
10	Mixed agricultural and range	0.10	0.05
11	Rocky (low shrubs)	0.10	0.05

The fraction of each of the eleven categories was then calculated for each grid cell and domain. A separate land-use file was prepared for each nested-grid sub-domain. Much of the modeling domain is assigned to the agricultural and forest land-use categories.

Chemistry Parameters

In combination with the albedo/haze/ozone column file, two additional inputs determine the chemical rates used by UAM-V. Photolysis rates are calculated as a function of albedo/haze/ozone column, height, and zenith angle. Photolysis rates were calculated with the photolysis rates preprocessor program using the values of albedo, haze, and total ozone column for the full domain, as provided by the albedo/haze/ozone processor program.

Additional chemistry parameters determine the rates and temperature dependence for the remaining reactions. Chemical reaction rates, activation energies, and maximum/minimum species concentrations from the validation data of the CB-V chemical mechanism against smog chamber data, were used along with appropriate updates for the enhanced treatment of radical-radical termination reactions, isoprene, and toxics chemistry.

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6. Model Performance Evaluation

The first stage in the application of the UAM-V modeling system for ozone air quality assessment purposes consists of an initial simulation and a series of diagnostic and sensitivity simulations. These simulations are aimed at examining the effects of uncertainties in the inputs on the simulation results, identifying deficiencies in the inputs, and investigating the sensitivity of the modeling system to changes in the inputs. Model performance for each simulation is assessed through graphical and statistical comparison of the simulated pollutant concentrations with the observed data obtained from available monitoring stations located throughout the domain. The results of this comparison are used to assess whether the model is able to adequately replicate the air quality characteristics of the simulation period, and to determine whether additional diagnostic and sensitivity simulations are needed.

Once the results of the graphical, statistical, and sensitivity analysis show acceptable performance of the model for a given simulation, that simulation is called the “base-case” simulation and the modeling analysis moves to the next stage. This next stage consists of projection and modification of the emission inputs to assess the effects of emission changes on future air quality. Reasonable model performance is critical to reliable use of the modeling system for such an assessment. Thus considerable time and effort are spent in the design and conduct of the base-case diagnostic and sensitivity analysis and in the evaluation of the base-case simulation.

The base-case application of the UAM-V modeling system for the ATMOS modeling episode periods included an initial simulation, several diagnostic/sensitivity simulations, a final base-case simulation, and graphical and statistical analysis of each set of modeling results, including comparison with observed air quality data. This report presents the procedures and results of the base-case modeling analysis for the 29 August – 9 September 1999, 16-22 June 2001, and 4-10 July 2002 ATMOS episode periods. The discussion centers on ozone, the primary pollutant of interest.

For ease of reading, all figures and tables follow the text of this section.

August/September 1999 Episode

Initial Simulation Results

The initial simulation serves several purposes. Initial application of the UAM-V model can reveal format problems or simple errors in the input files or parameters. The results of this simulation provide a basis to check for problems in the input files and to guide the input review and refinement that occur throughout the base-case modeling effort.

For the ATMOS episode of 29 August- 9 September 1999, the initial simulation is characterized by some underestimation of the ozone concentrations for the Memphis, Nashville, and high-elevation Knoxville (GSM) monitoring sites. For 1-4 September, concentrations are underestimated throughout the domain, but overestimated in the Chattanooga area. Key statistical measures calculated using the hourly ozone data for Grids 1, 2 and 3 (refer to Figure 1-2) are all within the recommended ranges provided by EPA guidance for all of the simulation days, but indicate consistent underestimation of the ozone concentrations.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine possible improvements to the meteorological input fields, use of an alternative vertical layer structure, and improved representation of the initial and boundary conditions. Subsequent diagnostic and sensitivity simulations incorporated updates to the emission inventories and examined the sensitivity of the modeling system to uncertainty in the emissions (specifically, the biogenic emissions). In total, eight full and eight partial simulations were run as part of the base-case modeling analysis for the August/September 1999 simulation period.

Meteorology Related Diagnostic and Sensitivity Simulations

The meteorology related diagnostic and sensitivity simulations focused first on improving the MM5 results for selected simulation days, and then on examining and updating the postprocessing procedures used to transform the outputs from MM5 into inputs for UAM-V. The UAM-V process analysis technique was also used to support the diagnostic analysis for this simulation period.

As discussed in Section 4 of this document, we found that the initial application of MM5 for this simulation period did not adequately simulate the surface temperatures for key locations in the eastern portion of the ATMOS fine-grid modeling domain for 1-3 September. Temperatures were as much as 6 to 8 degrees (C) cooler than the maximum observed values for Nashville, Knoxville, and Chattanooga in the MM5 outputs. We reran the fine-grid simulation for these three days using an enhanced moisture-nudging coefficient (5×10^{-5}). This resulted in higher temperatures and much better agreement with the temperature observations for these as well as other areas.

The remaining meteorology related diagnostic and sensitivity simulations examined different options for postprocessing the MM5 results. Two diagnostic simulations addressed better use of the MM5 results for input to the UAM-V. Specifically, a new procedure for interpolating the vertical exchange coefficients (K_vs) from the MM5 levels to the UAM-V layer interface levels was applied. The vertical exchange coefficients were normalized, to ensure that the maximum value represented by MM5 was also represented in the UAM-V ready K_v fields. This resulted in some slight improvement of the simulated ozone concentrations at the Knoxville area sites (those located in more varied terrain). Similarity theory was applied to estimate surface wind speed (and average winds within the lowest UAM-V model layer). This also resulted in a slight improvement of the ozone concentrations. Both of these changes to the MM5 postprocessing procedures were retained for the final base-case simulation.

Two simulations examined the sensitivity of the simulation results to the specification of postprocessing parameters. First, the MM5 postprocessing procedures include some nominal smoothing of the wind fields. Specifically, four passes through a 4-point smoother is typically applied. To examine whether this affected the transport characteristics of the wind fields, especially for the urban plumes, the usual smoothing of the wind fields was removed. Second, a different (and more stringent) divergence minimization criterion was used to determine the effects of this somewhat arbitrary parameter on the simulation results. In both, cases the changes to the simulated ozone concentrations were very small. These changes to the postprocessing parameters/assumptions were not retained for the final base-case simulation.

Modeling Domain Related Diagnostic Simulation

To examine the causes of higher than observed ozone concentrations during the nighttime hours for some of the monitoring sites, the lowest layer of the model was divided into two layers, creating an additional surface layer with a 25 m thickness. The idea was that a thinner surface layer would better simulate the titration of ozone during the nighttime hours by NO emissions, and thus the lower ozone concentrations during these hours at the urban sites. The results showed very little difference in ozone concentrations, both domain-wide and at the monitoring sites. The UAM-V layer structure was not changed as a result of this diagnostic test.

Initial and Boundary Condition Related Diagnostic and Sensitivity Simulations

It is usual during the course of a diagnostic analysis to confirm that the effects of the initial and boundary conditions are minimal and that the uncertainty inherent in both of these inputs does not overwhelm the effects of emissions or confound the effects of the emissions changes. Several diagnostic and sensitivity simulation were conducted for the August/September 1999 ATMOS simulation period to examine and refine these inputs.

The initial conditions represent the concentrations of all modeled species for all grid cells at the initial simulation time. We examined the sensitivity of the modeling results to the specification of the initial conditions and attempted to improve the representation of the initial pollutant values at the monitoring site locations. We re-interpolated the observations to the domain using a smaller radius of influence, thus limiting the influence of the observations to a smaller area around the monitors. The change in simulated ozone concentration due to the change in initial conditions was limited to the first two (start-up) days. The initial ozone concentrations, however, were not better represented.

The boundary condition sensitivity simulations examined the setting of the ozone boundary concentration. The UAM-V uses a self-generating ozone boundary condition approach in which the user must specify the initial value for ozone and then it is calculated each for each day as the average of the simulated ozone concentrations aloft – for the final hour of the previous day and averaged over the entire modeling domain. This approach is discussed in more detail in Section 5 of this document. Values of 40, 55, 65, and 75 ppb were tested. The first three values were the result of running the UAM-V and examining the level at which the ozone values remained steady after several days of simulation. The fourth value was based on the analysis of aircraft data from the 1995 Southern Oxidant Study (over Nashville) and was used primarily to examine whether higher ozone aloft would improve the agreement with the observed values at the higher elevation sites in the GSM National Park. Increasing the ozone boundary value from 40 to 55 to 65 ppb generally increased ozone concentrations throughout the domain, and provided slightly higher values and slightly improved model performance for monitoring sites within the ATMOS Grid 3 domain. The site-specific ozone concentrations were increased by at most about 5 ppb, when the ozone boundary value was changed from 40 to 65 ppb. Since other parameters were also changed in between this change in boundary values, the 5 ppb value is just an estimate. A value of 65 ppb was used for the base-case simulation. Use of an even higher value improved the representation of the ozone concentrations for the higher elevation sites, but was not retained for the final base-case simulation.

Emissions Related Diagnostic and Sensitivity Simulations

Several updates to the emissions inventories were incorporated into the base-case modeling for this simulation period. These included the use of the MOBILE6 model for the estimation of emissions from on-road mobile sources; updated point source emissions, including for electric generating unit and industrial sources; updated VMT estimates; and updated biogenic emissions (using newly released high-resolution crop/land-use data). These were incorporated throughout modeling analysis. One additional emissions related sensitivity simulation was conducted to examine the effects of uncertainty in the biogenic emission on the modeling results. In this simulation isoprene emissions were increased by 50 percent and the model was rerun for the first 6 days of the simulation period. This resulted in an increase in the simulated ozone concentrations of about 5 to 10 ppb (in some cases greater), especially downwind of the urban areas (where NO_x emissions are also present). These results highlight that some of the uncertainty in the modeling results is due to the known uncertainty in the biogenic emissions.

Process Analysis

The UAM-V process analysis technique was used to examine and quantify the importance of the various simulation processes to the base-case simulation results for the August/September 1999 simulation periods and to aid in the diagnosis of model performance issues. The UAM-V process analysis feature increases the amount of information that is saved during a photochemical simulation. In addition to the standard UAM-V output (the net species concentrations), additional information is saved indicating the individual contributions of the various physical and chemical process to the net concentrations. This additional information that is saved represents and quantifies the contributions from the following processes: chemistry, dry deposition, addition of material from the UAM-V plume-in-grid submodule, vertical advection, horizontal advection and diffusion (combined), and vertical diffusion.

The process analysis results suggest that all three of the expected primary ozone formation pathways contribute to the high simulated ozone concentrations in the area of interest:

- Ozone is produced aloft and transferred down to the surface by vertical diffusion and vertical advection.
- Local photochemical production of ozone also contributes to the daytime ozone levels.
- Some horizontal, perhaps regional-scale, transport, is also indicated.

Among the contributing processes, horizontal advection is most variable among the sites and the days. This suggests that some of the site-to-site and day-to-day variation in model performance is related to a similar variation in wind direction accuracy.

The results also indicate that the representation of the terrain, and specifically, the terrain-generated airflow features is important to good model performance at the GSM sites. Vertical advection (both positive and negative) is more important for these sites than for the other sites included in the analysis.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected (given the limitations of the data and modeling tools).

Assessment of Model Performance

We employed a variety of graphical and statistical analysis techniques to assess model performance for the ATMOS simulations. In presenting the results of this assessment, we first focus on 1-hour ozone concentration patterns and statistical measures for the full modeling domain and each subdomain. This provides perspective on regional-scale model performance and whether the model is able to capture day-to-day variability in the concentration patterns and values. We then examine the hourly concentrations for each area and site of interest. It is important that the model capture the hourly variations and 1-hour peaks in order to reliably represent the 8-hour average values. We then examine the performance of the model in representing 8-hour ozone concentrations throughout the domain and for each area and site of interest.

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-1 displays daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the August/September 1999 simulation period. The isopleths represent the 1-hour maximum simulated ozone concentrations and the numerical values represent the corresponding maximum observed concentrations. The domain-wide maximum and minimum values are provided in the upper right-hand corner of the plot. Note that the simulated values are derived from the results for all grids, not just Grid 1. These plots emphasize the variability of the concentrations throughout the region (both simulated and observed) that are attributable to the variable distribution of emissions sources. Notice that for areas covered by finer grids, the higher resolution translates into additional complexity in the ozone concentration patterns.

Figure 6-2 gives a closer look at daily maximum simulated ozone for Grid 3. The contours are reasonably consistent with the observed values with some notable underestimation of ozone in the Knoxville and GSM areas on several of the simulation days. Packed contours are often visible where several closely located observed values span a significant range, indicating a steep gradient or peak in ozone concentration.

Time-series plots comparing the simulated and observed values at the monitoring sites demonstrate how well the timing and magnitude of the simulated values matched the observations. The time-series plots in Figure 6-3 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. In these plots, the boxes represent the observed values, the solid line represents the simulated values (interpolated to the monitoring site location), and the shaded areas represent the range of concentrations in the nine cells surrounding the grid cell in which the monitoring site is located. Plots for all days span two pages.

Overall the time series show fair to good model performance for most sites on most days. For the Memphis area, the simulation follows the observed diurnal cycle fairly well, with some underestimation on the 4th and 7th in particular. The high peak value on the 3rd at Marion is captured by the nine cells around the site, represented by a relatively wide shaded region, though the modeled peak at the site's own grid cell is rather low. The Nashville time series show some daytime underestimation and nighttime overestimation, and one incident of daytime overestimation at Rockland Road on the 1st of September. The model does a generally good job of reflecting the observed ozone profile, including double peaks and nighttime cleanout. The model has greater difficulty at the Knoxville sites, predicting a flatter profile than observed for several sites. For other sites, the profile is similar but the model underestimates peak values on some days. For Chattanooga, results are generally good with less or later overnight ozone clear-out on some days, and some underestimation of high values. For the Tri-Cities area the model shows good performance for the first half of the episode, overestimation of some low daytime values on the 5th and the 6th, and an unrealistic peak of about 200 ppb at Kingsport on the 9th.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-4. These show reasonable correlation between simulated and observed values, with typically overestimation of low values and underestimation of high values.

Table 6-1 defines the statistical measures used to evaluate the model's ability to represent 1-hour ozone. While there are no strict criteria regarding what constitutes acceptable model performance, EPA guidance provides recommended ranges for the following: domain-wide unpaired accuracy of the peak (± 20 percent), normalized bias (± 15 percent) and normalized gross error (≤ 35 percent). We assume a consistent range for assessing the average accuracy of the peak (± 20 percent). For 8-hour ozone we also calculated two additional metrics: accuracy of the 8-hour maximum values averaged (1) over all sites in a given domain and (2) over all days for a given site; this should also be within ± 20 percent.

Table 6-2 provides the value of the 1-hour ozone metrics for all days of the August/September 1999 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for mediating the effects of uncertainty in initial conditions.

With one exception, the average accuracy, normalized bias, and normalized gross error are all within EPA recommendations for all grids and all days. The normalized bias shows a predominance of underestimation over all grids.

For 8-hour ozone, we focus on Grid 3. The domain-wide daily average accuracy is given in Table 6-3a, and the site-specific average accuracy values are given in Table 6-3b. In both cases, these measures are calculated over all non-start-up simulation days. These values are consistently within EPA suggested bounds. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). As expected, there is a tendency for a more positive value (less underestimation or more overestimation) when this metric is extended to the nine cells surrounding the site, as the metric then captures the high end of ozone gradients over a larger spatial range, and compares these to the same point-specific observed values. In this case the tendency to underestimation of 8-hour peak values is apparent even if the 9-cell average accuracy is examined, but the statistics are generally within or close to the recommended range. Kingsport is an exception, with the 9-cell overestimation driven by the extreme simulated peak near that site on the 9th.

June 2001 Episode

Initial Simulation Results

For the 16-22 June 2001 simulation period, the initial simulation showed good to very good representation of the observed ozone concentrations for most sites and days. Ozone concentrations are underestimated on the 20th and overestimated on the 22nd (the clean-out day). The statistical measures of model performance are within the EPA recommended ranges on all but the last simulation day. One problematic feature is that the timing and magnitude of the ozone concentrations at certain downwind sites is not well simulated. The diagnostic analysis examined the wind patterns, to see if better representation of the surface winds could improve the simulation profiles. We also refined the specification of the boundary conditions.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine the influence of initial conditions, meteorological inputs, and biogenic emissions.

Meteorology Related Diagnostic and Sensitivity Simulations

To examine the causes of the underestimation of ozone for 20 June, several sensitivity simulations were run for the 20^{th} only, testing the effect of changes to meteorological UAM-V inputs. In applying MM5 for this episode, we prepared two sets of inputs for 20 June – one set based on the third day of a three day simulation for 18-20 June, and one based on the first day of a three-day simulation for 20-22 June. In the initial simulation, the meteorological fields for 20 June were based on the second set of MM5 outputs. We also tested the use of the first set of outputs. We have found in past studies that for MM5, a different set of initial conditions (corresponding to a different start time) can result in improved representation of the meteorological conditions. This may be due to the build up of non-meteorological noise in the simulation as it progresses, or just that the alternate initial conditions provide a better basis for simulating the important features. The best results were achieved using the first set of MM5 outputs.

Reanalysis of the wind fields for 20 June, in which the resulting fields are recombined with the observed data to improve their representation in the field was also attempted. This did not improve the simulation results for this day. As an additional sensitivity test, we also modified wind fields by applying factors applied to each layer. This reduction in wind speed produced higher ozone for 20 June and allowed us to understand the causes of the underestimation of ozone for that day.

For this episode, we also tested and adopted the MM5 postprocessing procedures used for the August/September 1999 simulation period. Specifically, the K_v fields were normalized such that the maximum value in the vertical profile provided by MM5 was retained in the inputs to UAM-V. In addition, a similarity theory based approach was used to calculate the surface layer wind speeds.

Boundary Condition Related Diagnostic Simulation

The initial ozone boundary condition was increased from 40 to 65 ppb. While the first day of the initial simulation began with 40 ppb as the ozone value along the boundary, subsequent days generated boundary ozone values closer to 65 ppb. By setting first day's boundary ozone close to the apparent stable value arrived at by the model, we avoid arbitrary specification of the boundary condition (in the absence of upper-air pollutant concentration data). Small increases in the simulated ozone concentrations resulted from this change in the ozone boundary concentration.

Emissions Related Sensitivity Simulation

For this simulation period, we were concerned that higher than observed MM5-modeled temperatures were producing biogenic VOC values that were potentially biased high for some of the simulation days. To examine the effect on simulated ozone, we reduced the biogenic isoprene emissions by 25 percent. Ozone concentrations were reduced throughout the domain by as much as 2 to 5 ppb. This reveals the influence of possible uncertainties in the biogenic emissions. Other updates to the 2001 emissions were also incorporated into the inventory during the course of the base-case modeling analysis.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected (especially considering the schedule for the EAC modeling). The base-case simulation is described in the following section.

Assessment of Base-Case Model Performance

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-5 plots daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the June 2001 simulation period. The contours show reasonable agreement with observed values, with some evident overestimation in the coarse-resolution part of the full domain on the last few days of the episode.

Figure 6-6 displays daily maximum simulated ozone for Grid 3. Grid 3 shows a generally better match between observed and simulated data, relative to Grid 1. Peak simulated values on the June 20 and 21 plots appear near clusters of observed values whose range indicates a local ozone peak, but the contours seem to indicate overestimation at these sites.

Time-series plots in Figure 6-7 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. For Memphis, model performance as indicated by the time series appears very good. For Nashville, the model does not capture nighttime ozone clean-out for multiple sites, but the simulation matches daytime values reasonably well. The same is true for some Knoxville sites on some days. During the second half of the episode model performance is good to very good at all sites except Cades Cove, where the flat simulated profile misses the observed nighttime clean-out. Chattanooga and Tri-Cities also show mostly good model performance, with some underestimation on the 20th.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-8. The scatter plots indicate mostly overestimation, particularly of low values, with more underestimation of the highest values occurring on the 19th and 20th relative to the rest of the episode.

Table 6-4 provides the value of the 1-hour ozone metrics for all days of the June 2001 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for the simulation period. While unpaired accuracy is usually outside EPA recommended bounds, this may only indicate peak values not captured by the monitoring network. Only the last, clean-out episode day exceeds the EPA suggested range for average accuracy; high values at some sites are probably lingering in the modeled episode longer than in the historical episode.

The domain-wide daily average accuracy for 8-hour ozone is given for Grid 3 in Table 6-5a, and the site-specific average accuracy values are given in Table 6-5b. In both cases, these measures are calculated over all non-start-up simulation days. The overestimate of last day values indicated by 1-hour average accuracy is reflected in the 8-hour domain-wide average accuracy values. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). These site-specific metrics show the model overestimating in Memphis and Nashville, both over- and underestimating at Knoxville and Chattanooga, and underestimating at in the Tri-Cities area. The single-cell metric exceeds EPA recommendations only at Cades Cove. If the search for peak values extends to the 9-cell area, even higher values enter the calculation, and thus the 9-cell metric is outside EPA's suggested bounds for two additional sites.

July 2002 Episode

Initial Simulation Results

This third ATMOS simulation period was adapted for use in ATMOS following a review and evaluation of model performance for the ADEQ modeling analysis. The initial simulation for ADEQ showed good to very good performance throughout the domain, with some overestimation of ozone on the final simulation day. The diagnostic and sensitivity simulations mentioned below were done as part of the ADEQ modeling analysis; then the model was run only once for the ATMOS modeling domain. The discussion of model performance refers to this run.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine the influence of initial//boundary conditions, meteorological inputs, and biogenic emissions.

The second simulation, increased the first-day ozone boundary condition from 40 to 60 ppb, after consideration of model-generated boundary conditions in the same way as described above for the June 2001 episode.

In parallel to the June 2001 simulation, we also tested the influence of biogenic emissions and meteorological fields, respectively. We incorporated a 25% reduction in low-level ISOP emissions. We also tested and adopted the use of the ATMOS MM5 postprocessing procedures.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected. The inputs for ADEQ base-case simulation were then adapted to the ATMOS domain.

Assessment of Base-Case Model Performance

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-9 plots daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the July 2002 simulation period. The contours and observed values on these plots are reasonably matched, with packed contours—steep simulated ozone gradients—in regions of multiple monitoring sites, where high values are likely to be seen in general. For these days the observed values are somewhat lower than the contours predict, with more complex patterns in the high-resolution part of the grid, best examined in the next set of plots.

Figure 6-10 displays daily maximum simulated ozone for Grid 3. The fine grid contours show multiple high ozone peaks, roughly corresponding to nearby high observed values in some instances, although some local peaks are not covered by the monitoring network. The time series plots provide a closer view of the sites of interest.

Time-series plots in Figure 6-11 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. For Memphis and Nashville, these plots show generally good to very good model performance, with some overestimation of nighttime values. For Knoxville, simulated ozone cuts a flatter-than-observed profile for Cades Cove, and to a lesser degree Cove Mountain and Clingman's Dome. In general the time series show good representation of the Knoxville sites during the latter half of the episode, with some underestimation of nighttime values. Chattanooga time series show good model performance, as do the time series for Tri-Cities during the second half of the episode.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-12. The scatter plots show a tendency to overestimation on most days, with more of a balance on days with more high observed values.

Table 6-6 provides the value of the 1-hour ozone metrics for all days of the July 2002 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for the simulation period. Average accuracy is within the recommended range for all days for Grids 2 and 3, and for all but one day for Grid 1. Both underestimation and overestimation occurs throughout the episode.

The domain-wide daily average accuracy for 8-hour ozone is given for Grid 3 in Table 6-6a, and the site-specific average accuracy values are given in Table 6-6b. In both cases, these measures are calculated over all non-start-up simulation days. Domain-wide average accuracy is generally good, except for the overestimation on the last day, when observed ozone values are lower. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). These metrics show good model performance for the Memphis, Chattanooga, and Tri-Cities sites. There is a tendency to overestimate at the Nashville sites and at Cades Cove in Knoxville, probably during nighttime values, although the statistics incorporate a 40 ppb cut-off.

Composite Analysis for Site-Specific 8-Hour Ozone

Modeling results for all three episode combined are used in the attainment test to calculate the relative reduction factors and estimated future-year design values (this is discussed in Section 8 of the report). Table 6-8 summarizes model performance for each site using all three of the simulations periods and the site-specific unpaired accuracy metric. For the most part, the metrics fall squarely within the EPA suggested bounds for acceptable performance. Overall the simulations tend to underestimate at Memphis, Knoxville, Chattanooga, and Tri-Cities, and both over- and underestimate at Nashville.

These results indicate that the combined use of days provides an excellent basis for application of the attainment test procedures.

Table 6-1.
Metrics Used for Model Performance Evaluation for the ATMOS Modeling Analysis

Metric	Definition
Threshold value	The minimum observation value used to calculate statistics
Maximum observation (ppb)	Maximum concentration at an observation site
Maximum domain-wide simulation (ppb)	The maximum simulated concentration in the domain
Mean observation value (ppb)	The average observed concentration above the threshold value
Mean simulation value (ppb)	The average simulated concentration corresponding to observations above the threshold
Unpaired accuracy of the peak	$\frac{S_{Max} - O_{Max}}{O_{Max}}$ where S_{Max} is the maximum simulated value and O_{Max} is the maximum observation.
Average accuracy of the peak	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_{Ml} - O_{Ml})\Big/O_{Ml}$ where S_{Ml} and O_{Ml} are the maximum simulated and observed values at site l.
Normalized bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/O_l$ where N is the number of data pairs, and S_l and O_l are the simulated and observed values at site l, respectively.
Normalized gross error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/O_l$
Root mean square error (ppb)	$\sqrt{\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)^2}$

Table 6-2a.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	110	110.2	38.9	43.0	0.2%	-0.9%	-8.5%	22.9%	15.9
8/30	178	133.3	36.0	48.5	-25.1%	8.9%	-1.3%	20.6%	15.5
8/31	171	125.1	35.2	47.1	-26.8%	4.7%	-1.3%	21.7%	16.1
9/1	127	151.5	40.0	48.0	19.3%	-2.8%	-5.8%	20.3%	16.1
9/2	166	168.0	40.4	47.1	1.2%	-7.6%	-11.2%	26.4%	24.0
9/3	144.4	155.8	40.0	46.1	7.9%	-13.5%	-14.5%	27.1%	24.3
9/4	143	172.7	40.3	49.1	20.8%	-6.2%	-11.9%	24.4%	21.2
9/5	123	132.8	34.9	48.3	7.9%	4.0%	-10.5%	28.9%	24.9
9/6	155	120.5	34.0	49.6	-22.3%	12.4%	7.4%	23.8%	16.1
9/7	137	154.8	32.2	49.5	13.0%	15.5%	10.7%	25.1%	17.6
9/8	135	151.0	33.6	46.9	11.9%	6.5%	-1.7%	30.2%	22.7
9/9	117	202.3	30.5	46.8	72.9%	16.3%	8.3%	26.8%	17.3

Table 6-2b.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	105	110.2	44.2	43.4	5.0%	-12.0%	-14.5%	20.7%	15.8
8/30	116	133.3	44.1	48.4	14.9%	1.4%	-3.0%	15.6%	11.1
8/31	110	119.3	42.1	49.1	8.4%	-0.1%	-5.1%	20.2%	15.3
9/1	127	151.5	45.6	50.9	19.3%	-8.1%	-10.1%	20.2%	17.6
9/2	158	168.0	46.6	48.0	6.3%	-16.7%	-17.5%	29.2%	28.2
9/3	144.4	155.8	45.0	47.4	7.9%	-13.4%	-13.8%	29.6%	26.6
9/4	143	172.7	46.4	52.4	20.8%	-0.1%	-8.3%	25.6%	22.9
9/5	123	132.8	42.3	50.4	7.9%	-4.1%	-10.5%	23.4%	20.4
9/6	127	120.5	37.7	50.6	-5.1%	6.5%	3.5%	21.7%	16.1
9/7	137	154.8	39.0	50.5	13.0%	1.6%	0.8%	20.8%	17.2
9/8	135	151.0	39.9	48.9	11.9%	-5.3%	-9.3%	27.8%	23.2
9/9	115	202.3	33.2	45.9	75.9%	9.9%	1.6%	23.1%	15.6

Table 6-2c.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	105	107.9	51.2	46.3	2.8%	-16.1%	-18.7%	22.2%	17.0
8/30	116	126.8	52.3	50.8	9.3%	-9.1%	-8.0%	14.2%	11.2
8/31	110	119.3	48.7	51.7	8.4%	-5.7%	-7.6%	19.7%	15.4
9/1	127	151.5	50.5	53.1	19.3%	-9.3%	-12.4%	21.5%	19.8
9/2	158	168.0	52.0	53.9	6.3%	-15.8%	-14.4%	23.8%	23.8
9/3	144.4	155.8	47.7	50.9	7.9%	-10.2%	-8.4%	26.0%	23.5
9/4	131	172.7	51.3	55.0	31.8%	-4.2%	-6.2%	22.6%	20.1
9/5	123	132.8	47.8	52.6	7.9%	-9.4%	-9.6%	20.2%	19.6
9/6	127	120.5	44.6	53.3	-5.1%	-3.8%	-2.4%	20.9%	17.0
9/7	115	154.8	45.9	53.8	34.6%	-3.7%	-5.7%	21.7%	19.3
9/8	135	151.0	46.7	54.1	11.9%	-9.8%	-9.3%	24.9%	21.5
9/9	115	202.3	39.4	45.8	75.9%	1.4%	-8.1%	22.6%	16.5

Table 6-3a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; August-September 1999 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
31	-1.9%	2.6%
1	-10.1%	-3.6%
2	-13.7%	-6.7%
3	-8.6%	1.4%
4	-3.9%	2.9%
5	-10.4%	-5.6%
6	-2.2%	3.0%
7	-2.2%	5.6%
8	-10.2%	-3.0%
9	3.0%	14.1%

Table 6-3b.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; August-September 1999 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	-10.1%	-1.7%
Edmond Orgill Park, TN	-11.8%	-7.8%
Frayser, TN	-14.1%	-5.2%
Marion, AR	-7.6%	2.8%
Nashville EAC		
Cottontown Wright's Farm, TN	-21.1%	-16.1%
Dickson County, TN	-9.3%	-5.3%
East Nashville Health Center, TN	-18.2%	-2.9%
Fairview, TN	-9.3%	-4.9%
Cedars of Lebanon State Park	3.8%	6.8%
Percy Priest Dam, TN	-13.3%	-0.1%
Rockland Road, TN	-5.1%	-0.7%
Rutherford County, TN	-14.9%	-11.9%
Knoxville EAC		
Anderson County, TN	-1.6%	4.6%
Cades Cove, TN	-3.8%	-0.8%
Clingman's Dome, TN	-18.8%	-16.7%
Cove Mountain, TN	-22.9%	-20.7%
East Knox, TN	-9.7%	-6.5%
Jefferson County, TN	-2.0%	2.5%
Look Rock (1), TN	-19.5%	-14.9%
Look Rock (2), TN	-21.1%	-16.6%
Spring Hill, TN	-23.4%	-7.2%
Chattanooga EAC		
Chattanooga VAAP, TN	-9.6%	0.6%
Sequoyah, TN	-9.1%	-0.9%
Tri-Cities EAC		
Kingsport, TN	-2.3%	23.1%
Sullivan County, TN	-0.4%	9.6%

Table 6-4a.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	156	123.9	36.0	46.7	-20.6%	12.3%	12.0%	19.0%	12.9
6/17	100	131.6	44.7	54.8	31.6%	5.7%	6.4%	15.8%	11.7
6/18	137	147.6	49.4	56.5	7.7%	-2.0%	0.7%	15.4%	12.4
6/19	143	146.7	50.1	56.3	2.6%	-2.6%	-2.4%	17.1%	13.6
6/20	136	160.3	41.0	50.6	17.9%	-0.5%	-0.7%	21.7%	15.8
6/21	123	158.3	35.9	49.2	28.7%	7.7%	5.0%	23.3%	16.1
6/22	106	132.3	34.6	52.3	24.9%	26.3%	22.8%	28.6%	17.1

Table 6-4b.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	87	112.7	36.7	46.7	29.5%	12.0%	11.8%	18.2%	11.5
6/17	100	131.6	45.7	56.6	31.6%	3.5%	6.3%	15.0%	11.4
6/18	114	147.6	49.6	58.0	29.5%	-2.2%	1.3%	14.3%	11.6
6/19	121	146.7	49.8	56.7	21.2%	-3.2%	-1.6%	16.7%	13.8
6/20	119	160.3	44.3	52.0	34.7%	-5.6%	-3.3%	21.0%	16.3
6/21	123	158.3	39.7	52.4	28.7%	14.4%	10.3%	24.1%	17.0
6/22	93	132.3	34.1	52.9	42.3%	28.0%	27.8%	29.9%	17.7

Table 6-4c.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	87	111.6	38.0	49.5	28.3%	14.9%	14.7%	18.8%	11.5
6/17	100	130.9	48.2	59.1	30.9%	2.6%	4.5%	14.6%	10.8
6/18	114	147.6	50.9	61.9	29.5%	4.5%	5.5%	16.4%	13.6
6/19	110	146.7	51.8	57.1	33.3%	-4.9%	-4.1%	16.7%	14.2
6/20	115	160.3	48.5	55.4	39.4%	-4.2%	-2.9%	20.5%	17.0
6/21	108	158.3	42.7	57.4	46.6%	18.3%	13.6%	24.9%	17.7
6/22	82	127.3	34.3	54.5	55.3%	32.2%	27.9%	30.0%	17.4

Table 6-5a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; June 2001 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
18	5.4%	10.2%
19	-7.4%	-2.2%
20	-2.0%	6.8%
21	19.1%	25.9%
22	36.8%	42.7%

Table 6-5b.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; June 2001 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	5.7%	10.8%
Edmond Orgill Park, TN	1.0%	3.7%
Frayser, TN	7.4%	15.4%
Marion, AR	1.3%	7.1%
Nashville EAC		
Cedars of Lebanon State Park	0.6%	3.1%
Cottontown Wright's Farm, TN	10.4%	17.2%
East Nashville Health Center, TN	18.4%	38.3%
Fairview, TN	6.2%	8.2%
Percy Priest Dam, TN	6.3%	19.5%
Rockland Road, TN	19.4%	24.4%
Rutherford County, TN	0.5%	3.9%
Knoxville EAC		
Anderson County, TN	-5.4%	0.1%
Cades Cove, TN	24.4%	27.2%
Clingman's Dome, TN	-7.9%	-4.8%
Cove Mountain, TN	-9.9%	-6.6%
East Knox, TN	6.0%	12.3%
Jefferson County, TN	-1.3%	6.6%
Look Rock, TN	1.2%	5.6%
Chattanooga EAC		
Chattanooga VAAP, TN	6.2%	13.7%
Meigs County, TN	-12.2%	-6.5%
Sequoyah, TN	7.1%	12.3%
Tri-Cities EAC		
Kingsport, TN	-3.6%	4.5%
Sullivan County, TN	-8.2%	-0.3%

Table 6-6a.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	133.8	38.8	44.7	12.4%	-0.7%	-6.5%	22.8%	17.6
7/5	128	163.1	38.0	52.6	27.4%	13.9%	8.6%	21.7%	15.7
7/6	116	170.9	41.9	54.4	47.3%	10.5%	8.9%	22.0%	15.9
7/7	115	161.2	44.6	56.2	40.2%	6.4%	7.5%	19.5%	14.8
7/8	135	165.6	47.4	54.4	22.7%	-1.0%	-0.9%	19.3%	16.0
7/9	135	141.8	41.9	53.4	5.0%	4.1%	2.3%	21.1%	16.2
7/10	114	140.5	35.2	54.4	23.3%	23.9%	22.0%	28.6%	18.3

Table 6-6b.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	133.8	42.2	45.0	12.4%	-6.0%	-7.8%	22.8%	18.5
7/5	128	163.1	45.5	56.1	27.4%	3.1%	4.5%	19.7%	15.8
7/6	110	170.9	50.8	56.8	55.3%	-1.8%	-0.1%	18.3%	15.0
7/7	111	161.2	50.9	57.0	45.3%	0.2%	1.5%	16.5%	13.1
7/8	127	165.6	49.3	54.5	30.4%	-2.7%	-1.6%	18.6%	15.4
7/9	128	141.8	43.2	54.2	10.8%	5.6%	5.0%	20.9%	16.0
7/10	105	140.5	37.3	54.8	33.8%	18.5%	19.4%	28.2%	18.7

Table 6-6c.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	122.4	43.2	44.7	2.9%	-11.3%	-11.7%	22.2%	17.9
7/5	121	163.1	45.9	57.0	34.8%	5.7%	4.2%	19.7%	15.7
7/6	110	170.9	52.2	62.3	55.3%	5.2%	5.8%	18.3%	15.1
7/7	109	161.2	53.7	59.2	47.9%	2.7%	2.6%	18.3%	14.6
7/8	110	147.1	49.6	53.4	33.7%	-2.5%	-0.7%	18.4%	14.1
7/9	117	141.8	42.3	54.8	21.2%	11.7%	10.2%	24.3%	18.0
7/10	102	140.5	38.2	55.7	37.8%	18.1%	20.2%	27.8%	18.7

Table 6-7a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; July 2002 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
6	7.1%	12.5%
7	4.7%	9.9%
8	-0.6%	6.0%
9	15.6%	22.8%
10	27.8%	36.3%

Table 6-7b.
Site-Specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; July 2002 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	5.2%	7.9%
Edmond Orgill Park, TN	-8.8%	-5.0%
Frayser, TN	-3.7%	3.4%
Marion, AR	-4.7%	-1.0%
Nashville EAC		
Cottontown Wright's Farm, TN	-2.1%	4.4%
East Nashville Health Center, TN	37.0%	56.6%
Fairview, TN	14.1%	21.3%
Cedars of Lebanon State Park	17.0%	23.3%
Percy Priest Dam, TN	32.3%	45.9%
Rockland Road, TN	18.7%	24.2%
Rutherford County, TN	-2.6%	-1.2%
Knoxville EAC		
Anderson County, TN	-1.4%	2.1%
Cades Cove, TN	25.2%	29.1%
Clingman's Dome, TN	-12.5%	-9.0%
Jefferson County, TN	-4.8%	-0.1%
Knox County, TN	-5.1%	0.9%
Knoxville, TN	-6.2%	0.3%
Look Rock, TN	-4.6%	0.8%
Sevier County, TN	-9.9%	-4.9%
Chattanooga EAC		
Chattanooga VAAP, TN	4.6%	12.5%
Meigs County, TN	-10.0%	-1.9%
Sequoyah, TN	4.5%	10.5%
Tri-Cities EAC		
Kingsport, TN	-4.0%	7.5%
Sullivan County, TN	-5.2%	0.5%

Table 6-8.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; All Episodes Combined, Excluding Startup Days

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	-1%	4%
Edmond Orgill Park, TN	-7.9%	-4.2%
Frayser, TN	-6.1%	2.1%
Marion, AR	-4.6%	2.9%
Nashville EAC		
Cedars of Lebanon State Park	6.6%	10.4%
Cottontown Wright's Farm, TN	-8.8%	-3.0%
Dickson County, TN	-9.3%	-5.3%
East Nashville Health Center, TN	4.1%	21.4%
Fairview, TN	0.4%	4.9%
Percy Priest Dam, TN	2.8%	16.2%
Rockland Road, TN	7.0%	11.8%
Rutherford County, TN	-8.4%	-5.8%
Knoxville EAC		
Anderson County, TN	-2.3%	3.0%
Cades Cove, TN	8.9%	11.9%
Clingman's Dome, TN	-14.5%	-11.8%
Cove Mountain, TN	-16.4%	-13.2%
East Knox, TN	-4.6%	0.1%
Jefferson County, TN	-2.6%	2.9%
Look Rock (1), TN	-10.6%	-5.8%
Look Rock (2), TN	-21.1%	-16.6%
Spring Hill, TN	-17.7%	-4.7%
Chattanooga EAC		
Chattanooga VAAP, TN	-2.5%	6.5%
Meigs County, TN	-11.0%	-3.9%
Sequoyah, TN	-2.1%	4.9%
Tri-Cities EAC		
Kingsport, TN	-3.1%	13.6%
Sullivan County, TN	-3.9%	4.3%

Figure 6-1a.
Daily Maximum 1-Hour Ozone, Grid 1,
August 29, 1999

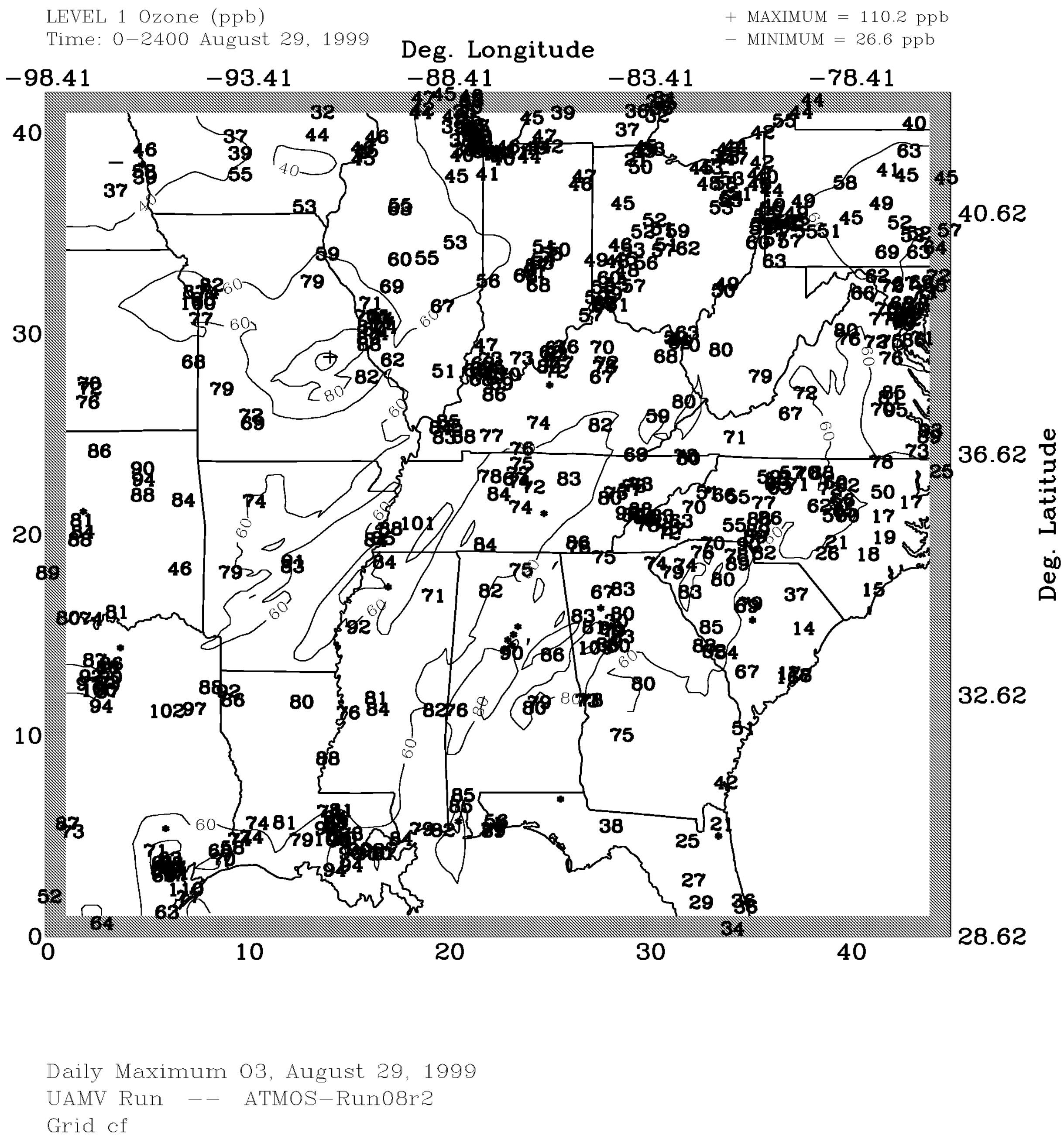


Figure 6-1b.
Daily Maximum 1-Hour Ozone, Grid 1,
August 30, 1999

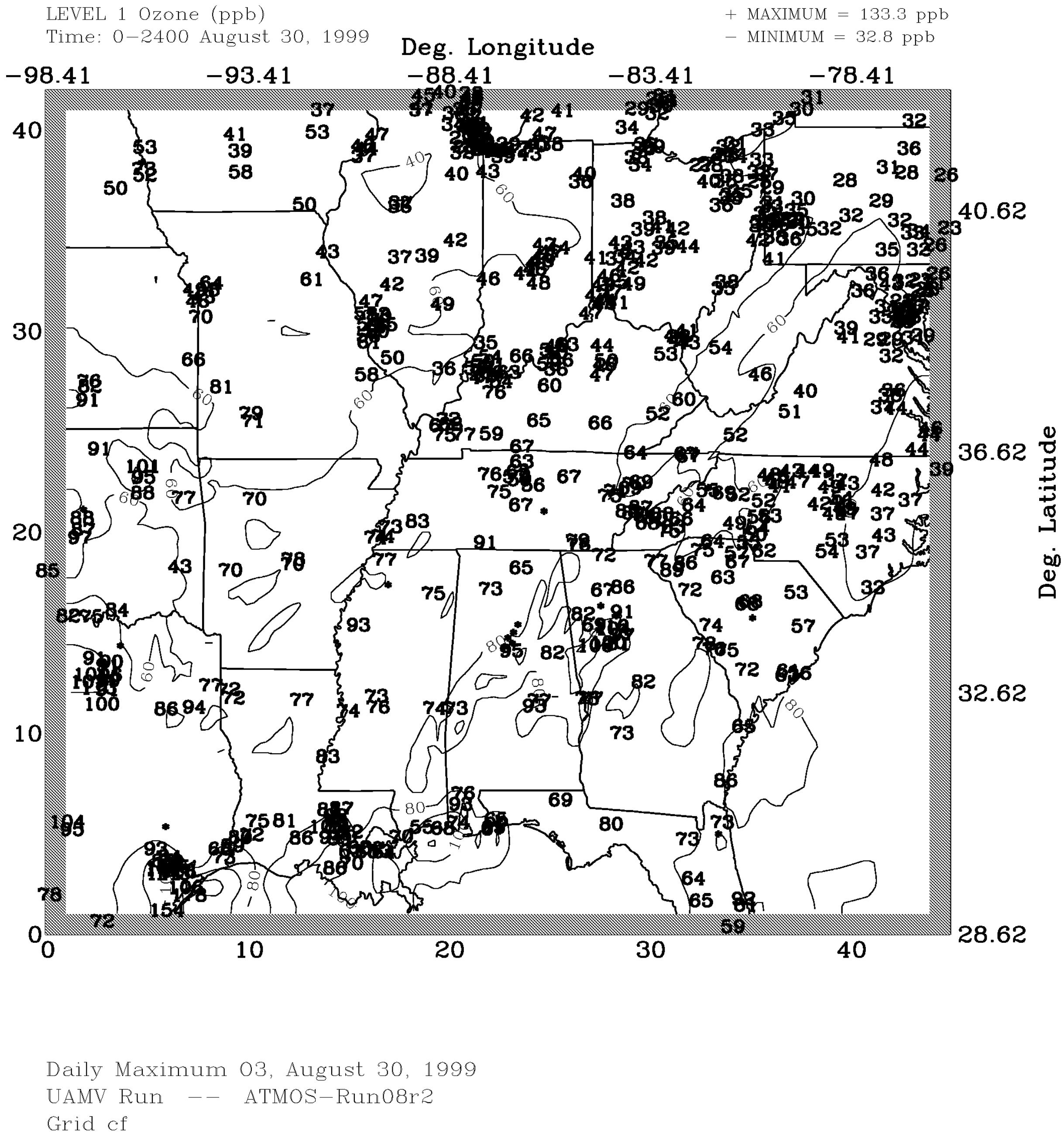


Figure 6-1c.
Daily Maximum 1-Hour Ozone, Grid 1,
August 31, 1999

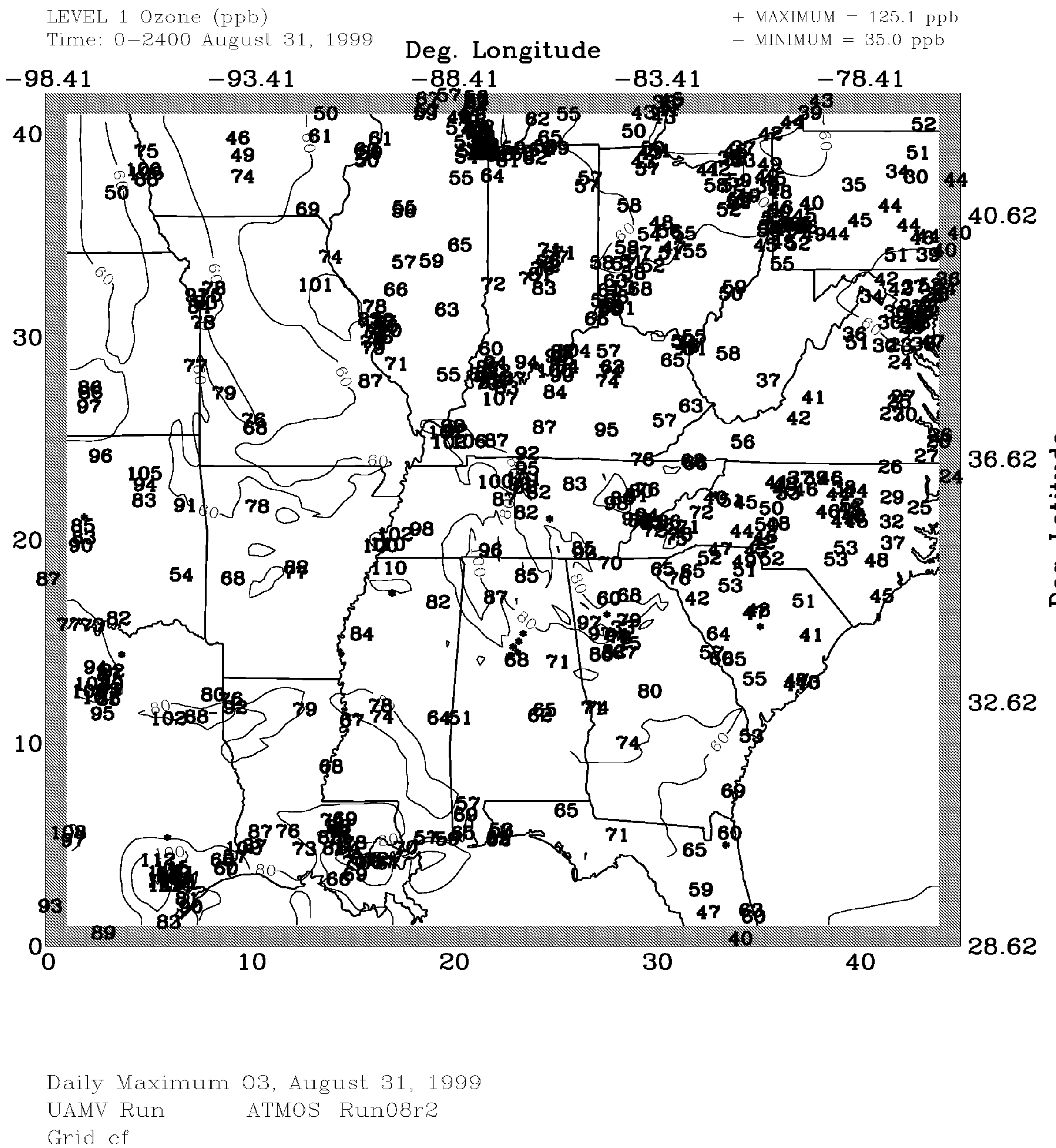


Figure 6-1d.
Daily Maximum 1-Hour Ozone, Grid 1,
September 1, 1999

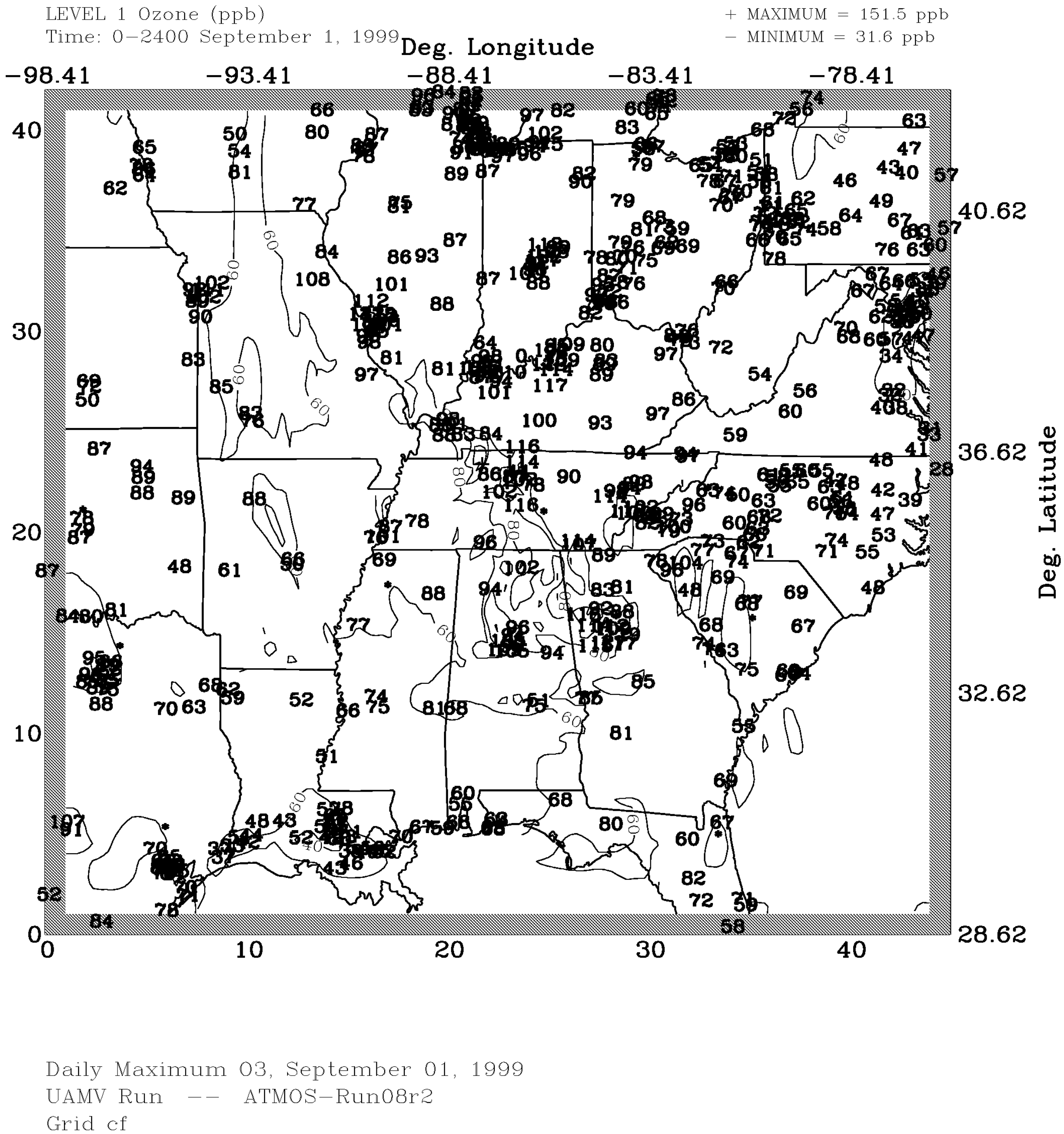


Figure 6-1e.
Daily Maximum 1-Hour Ozone, Grid 1,
September 2, 1999

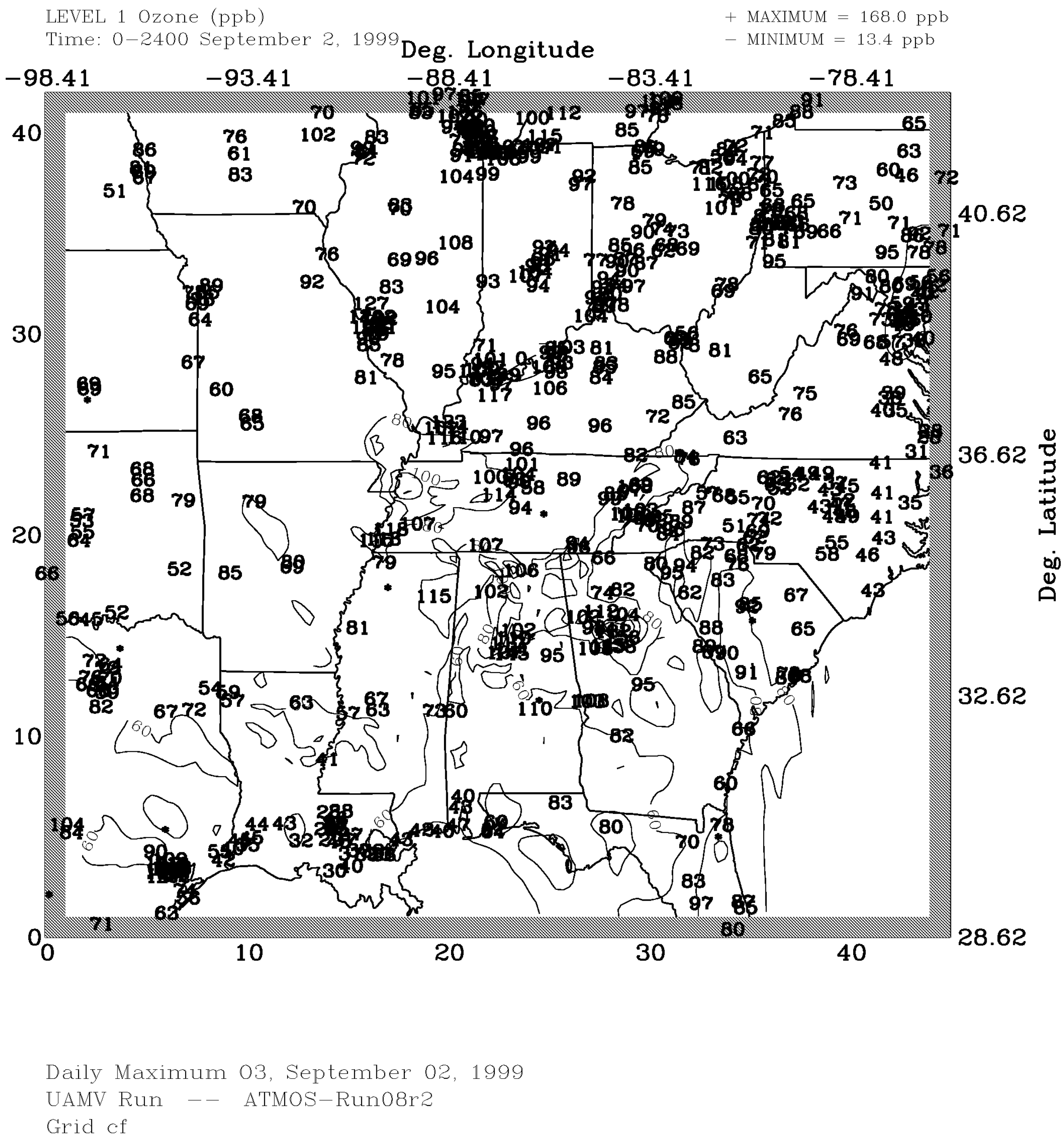


Figure 6-1f.
Daily Maximum 1-Hour Ozone, Grid 1,
September 3, 1999

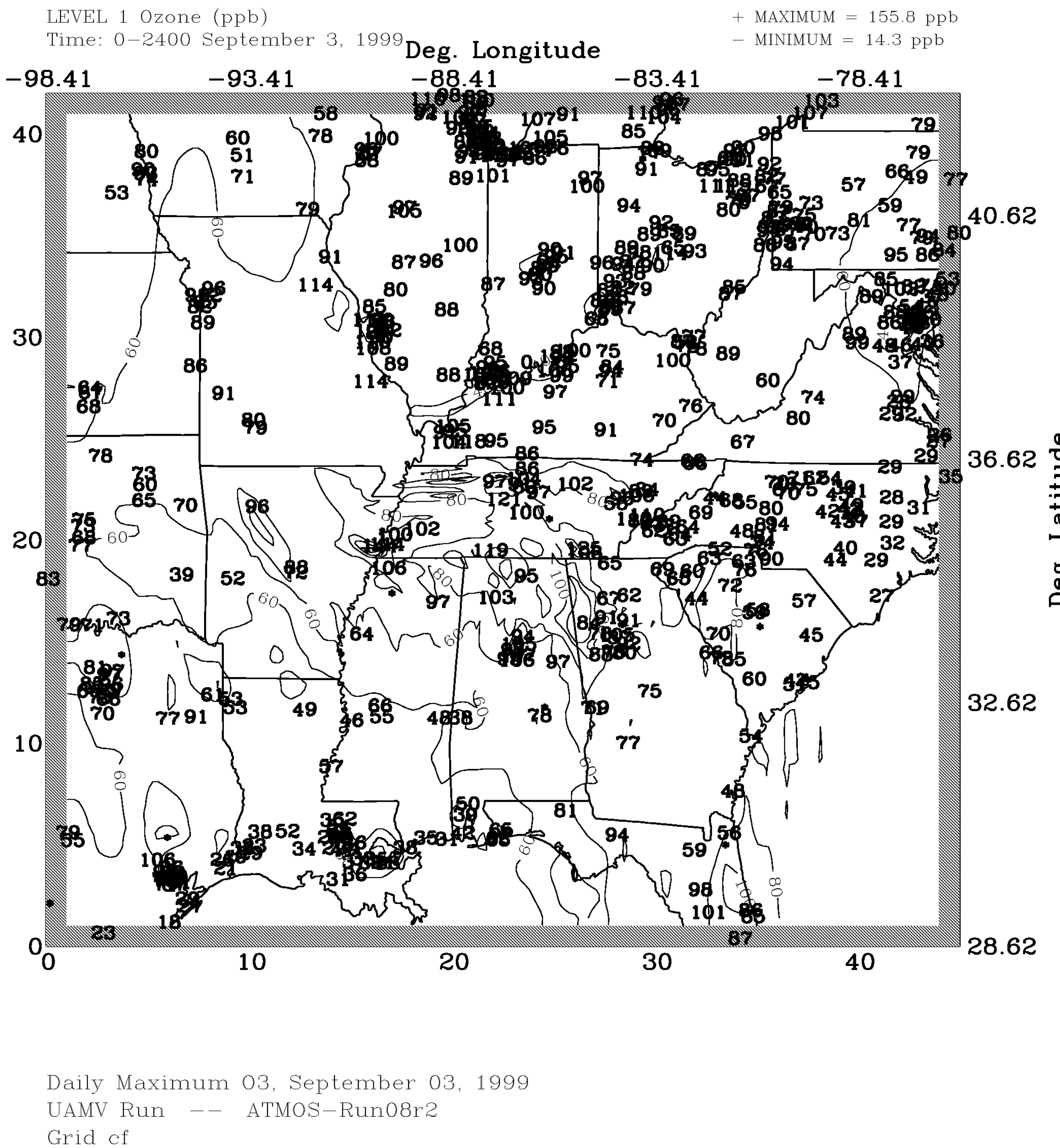


Figure 6-1g.
Daily Maximum 1-Hour Ozone, Grid 1,
September 4, 1999

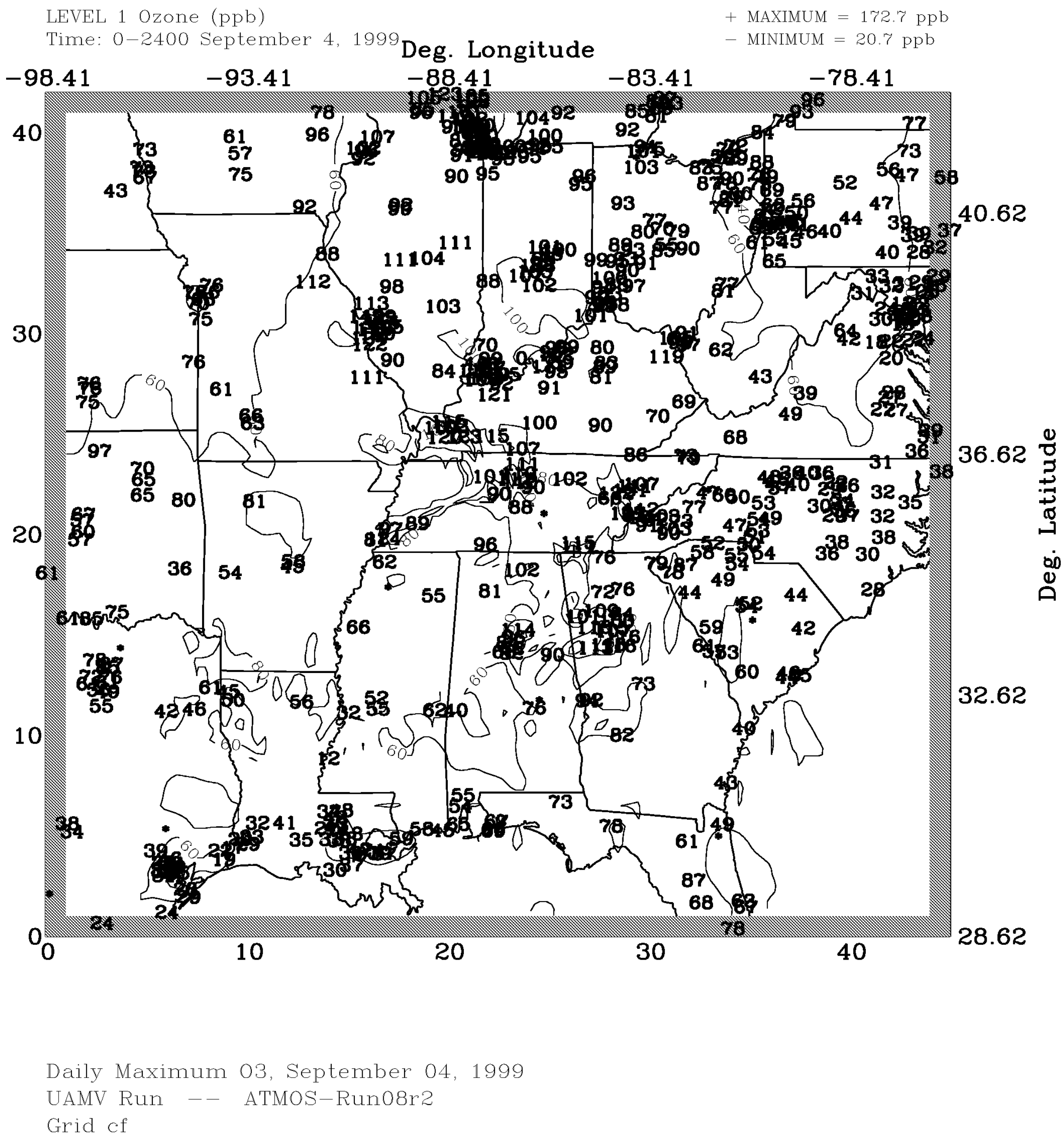


Figure 6-1h.
Daily Maximum 1-Hour Ozone, Grid 1,
September 5, 1999

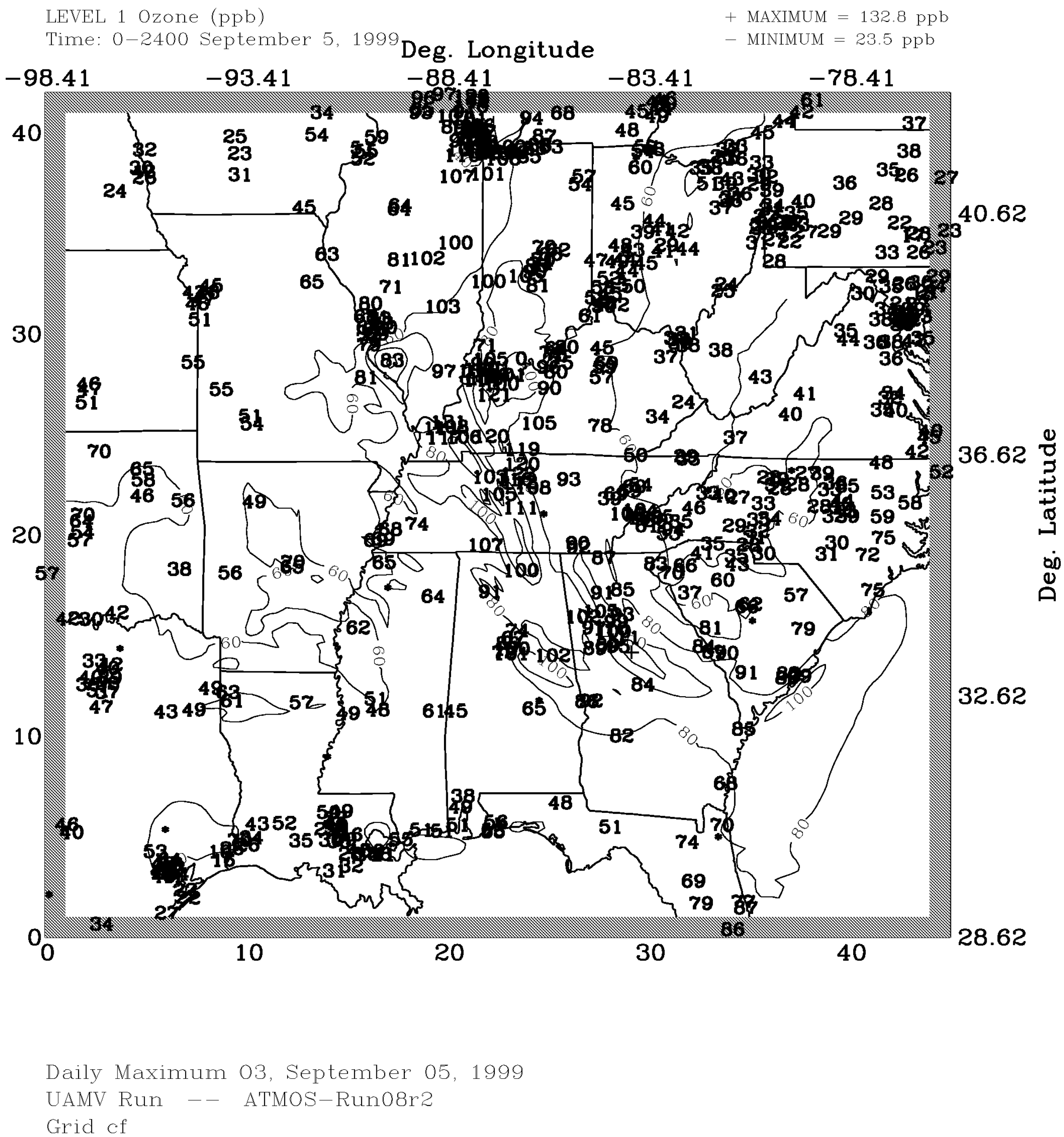


Figure 6-1i.
Daily Maximum 1-Hour Ozone, Grid 1,
September 6, 1999

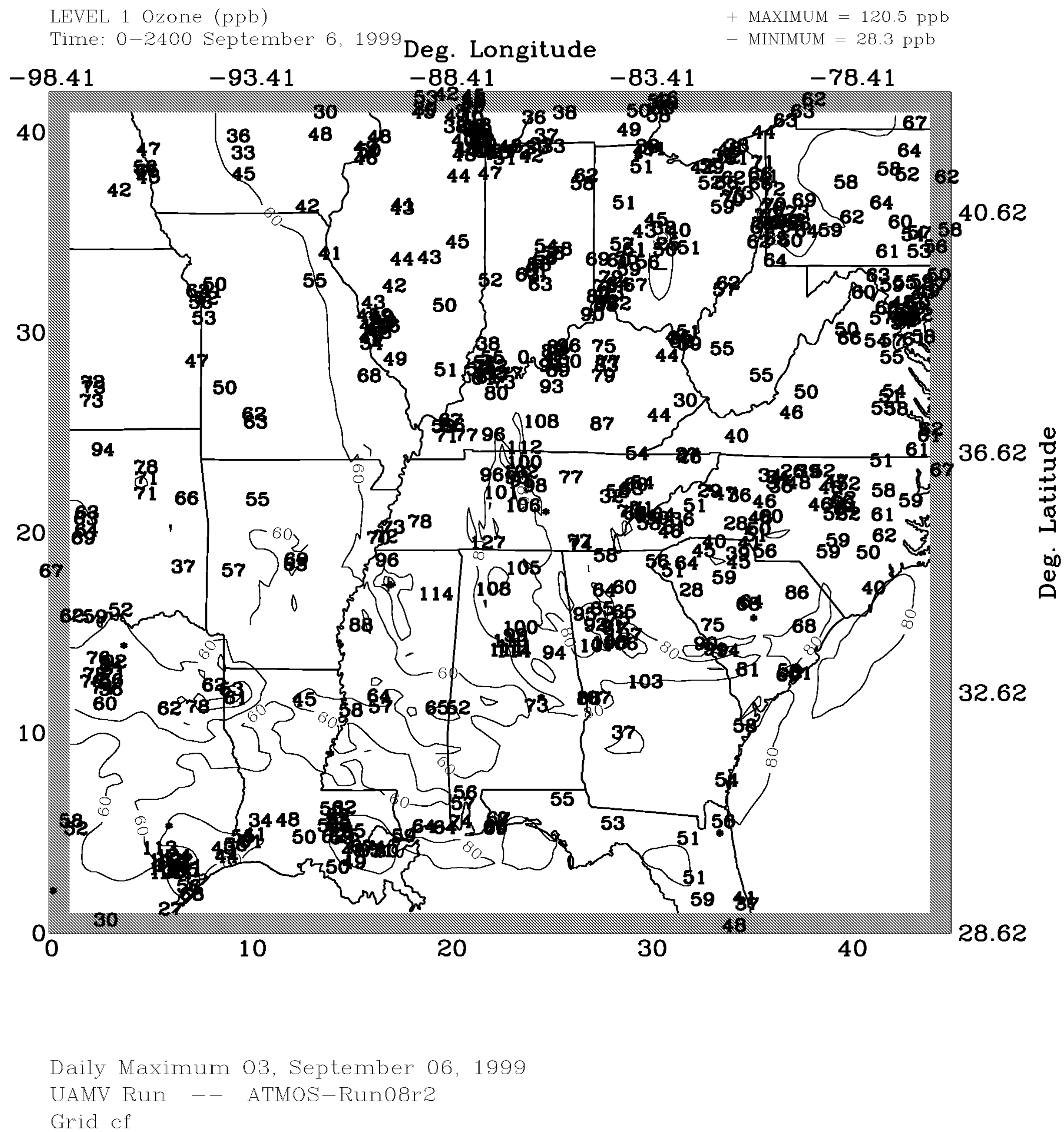


Figure 6-1j.
Daily Maximum 1-Hour Ozone, Grid 1,
September 7, 1999

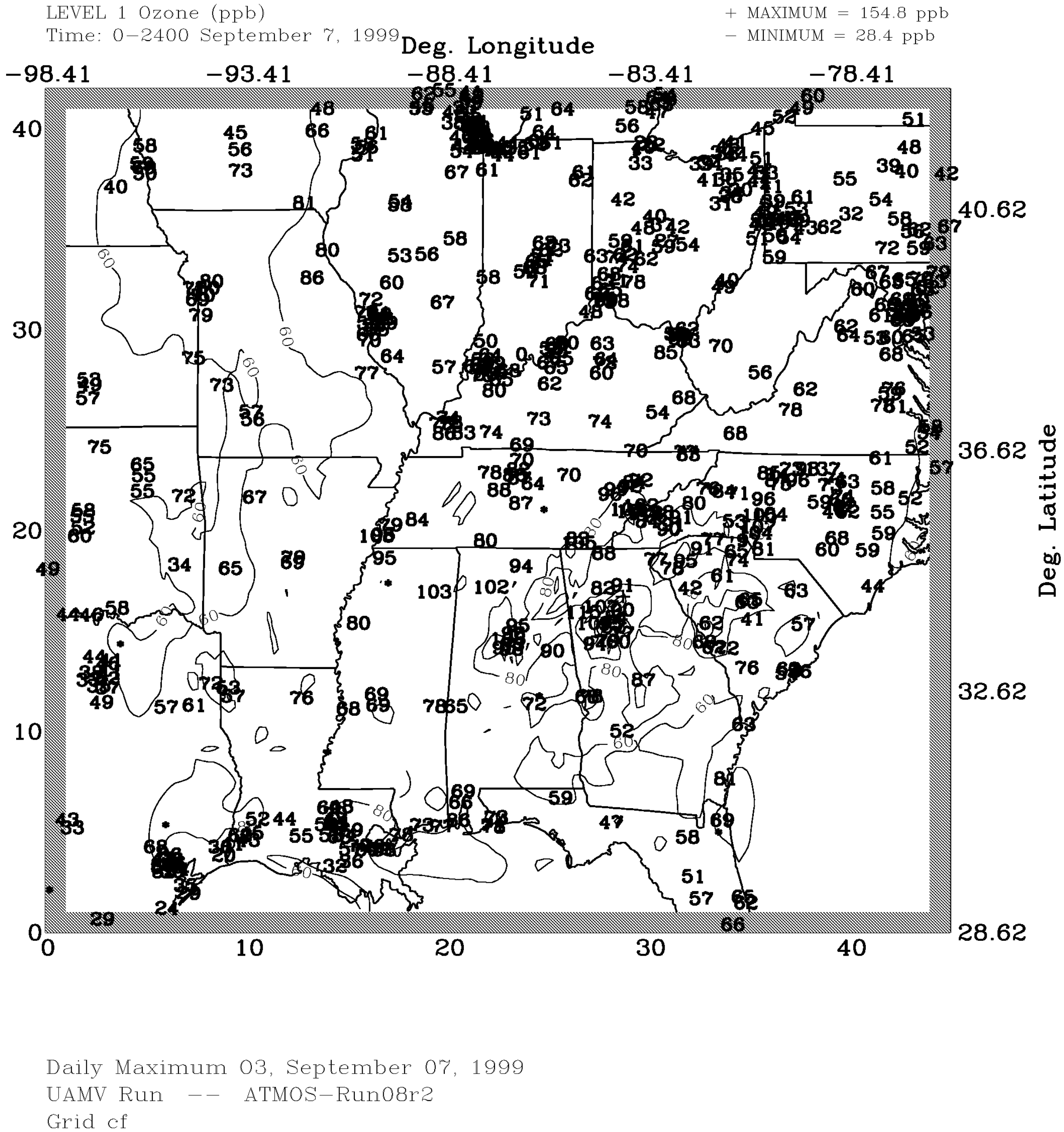


Figure 6-1k.
Daily Maximum 1-Hour Ozone, Grid 1,
September 8, 1999

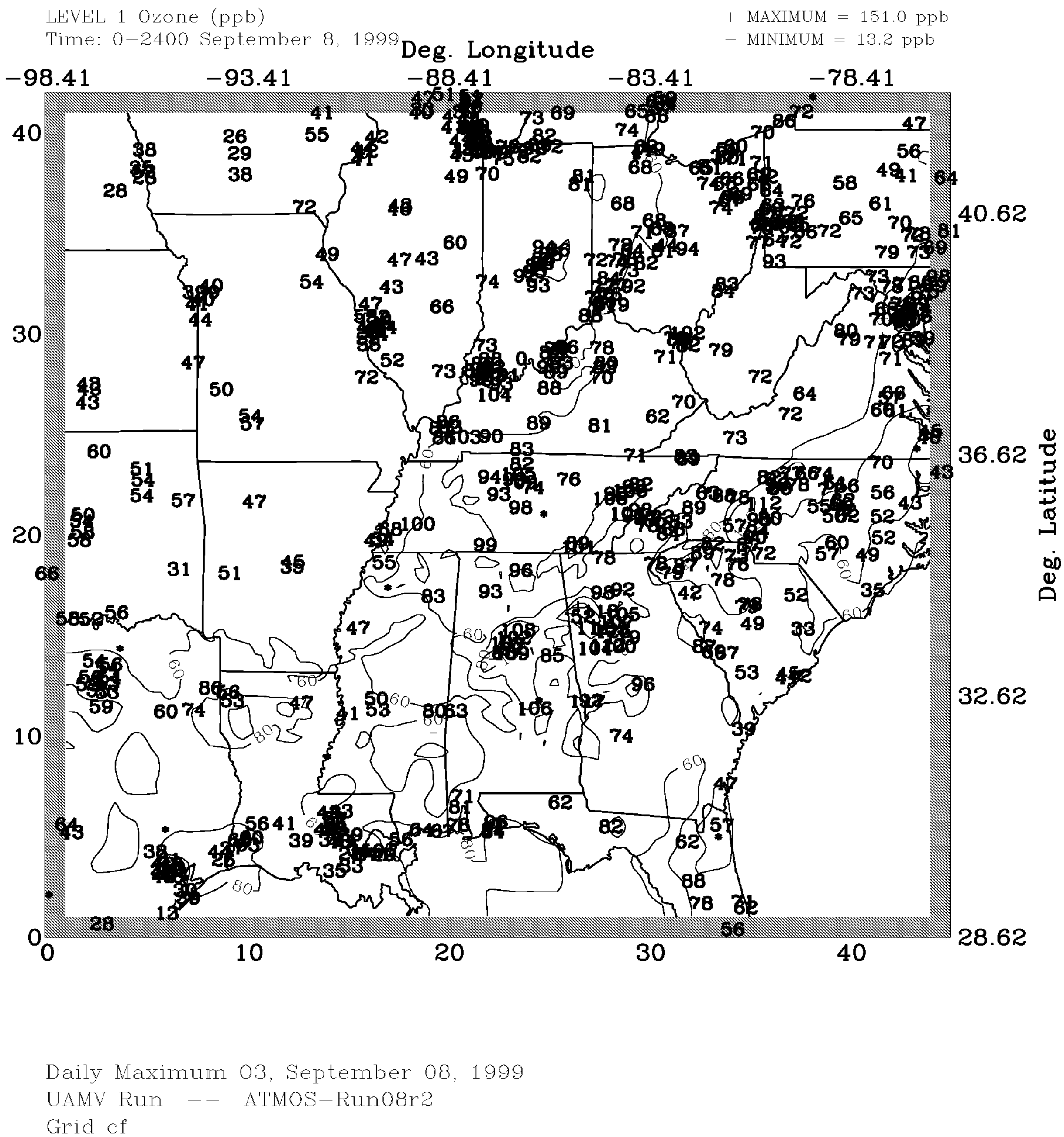


Figure 6-1l.
Daily Maximum 1-Hour Ozone, Grid 1,
September 9, 1999

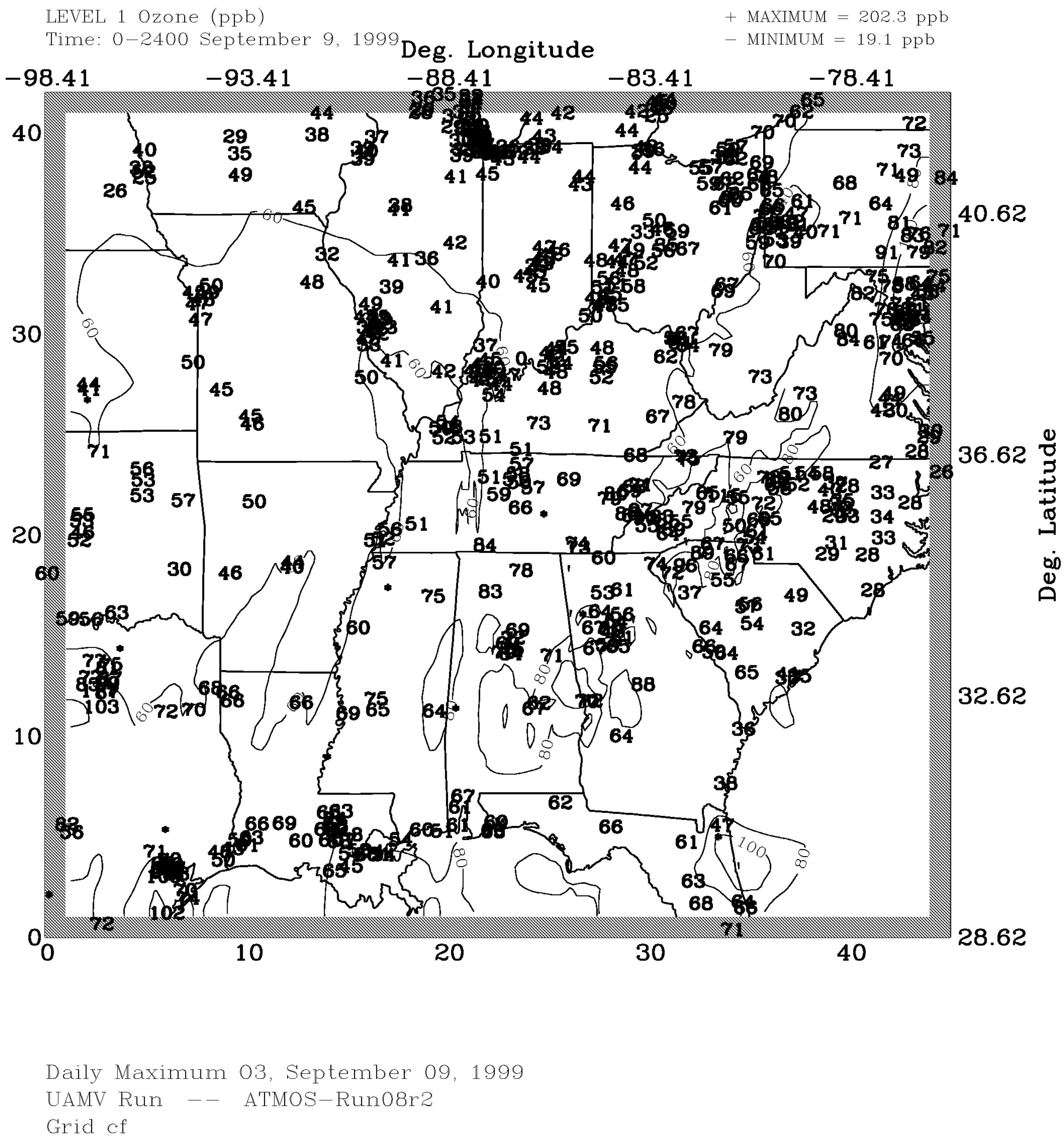


Figure 6-2a.
Daily Maximum 1-Hour Ozone, Grid 3,
August 29, 1999

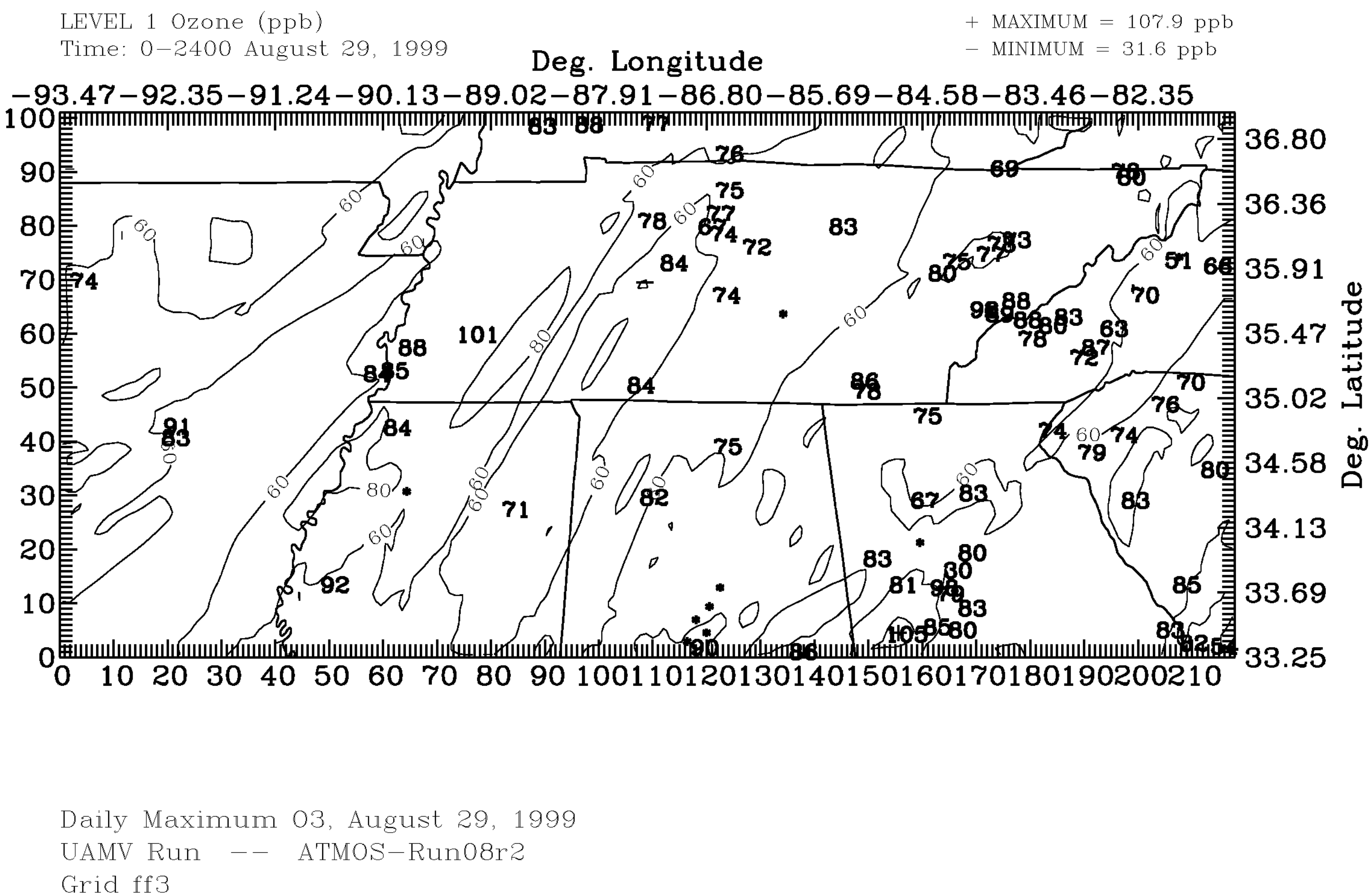
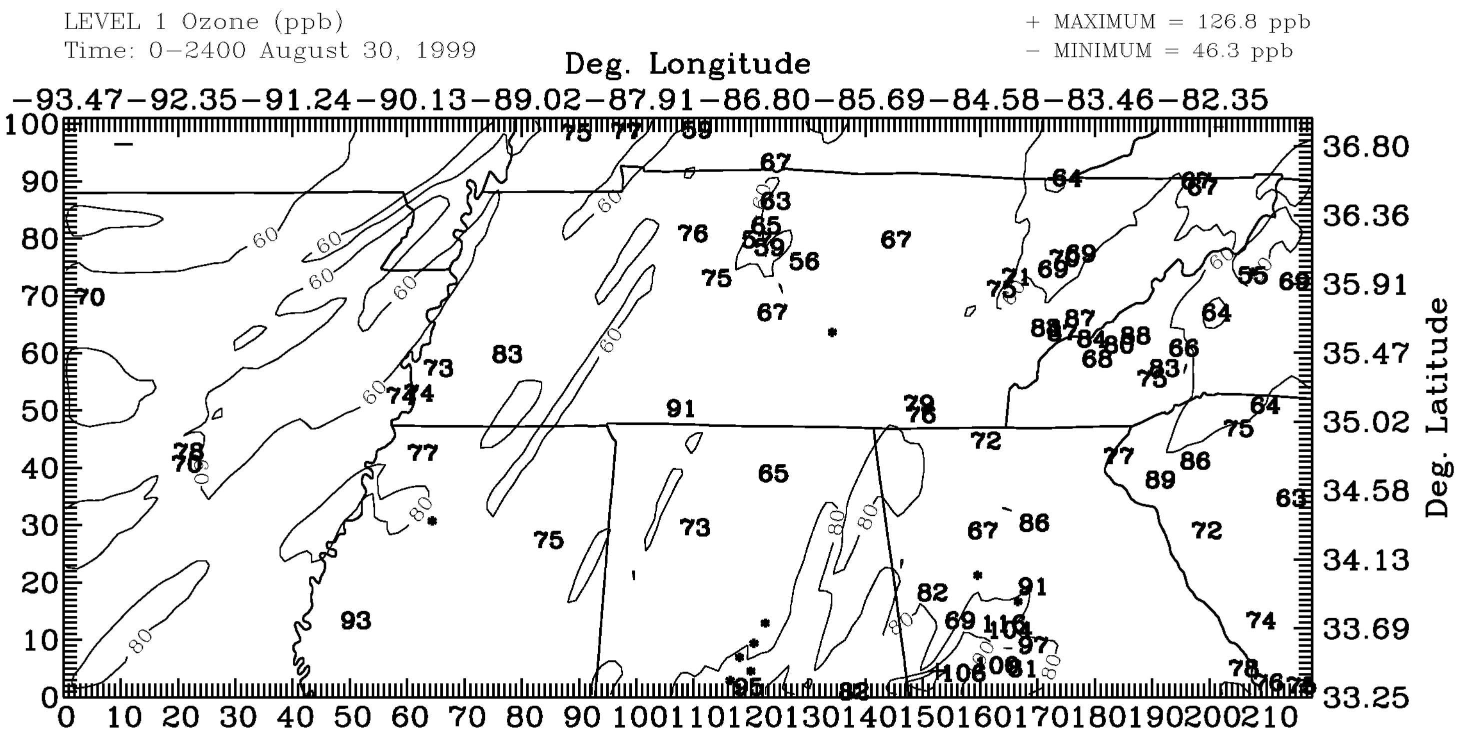


Figure 6-2b.
Daily Maximum 1-Hour Ozone, Grid 3,
August 30, 1999



Daily Maximum O3, August 30, 1999
UAMV Run -- ATMOS-Run08r2
Grid ff3

Figure 6-2c.
Daily Maximum 1-Hour Ozone, Grid 3,
August 31, 1999

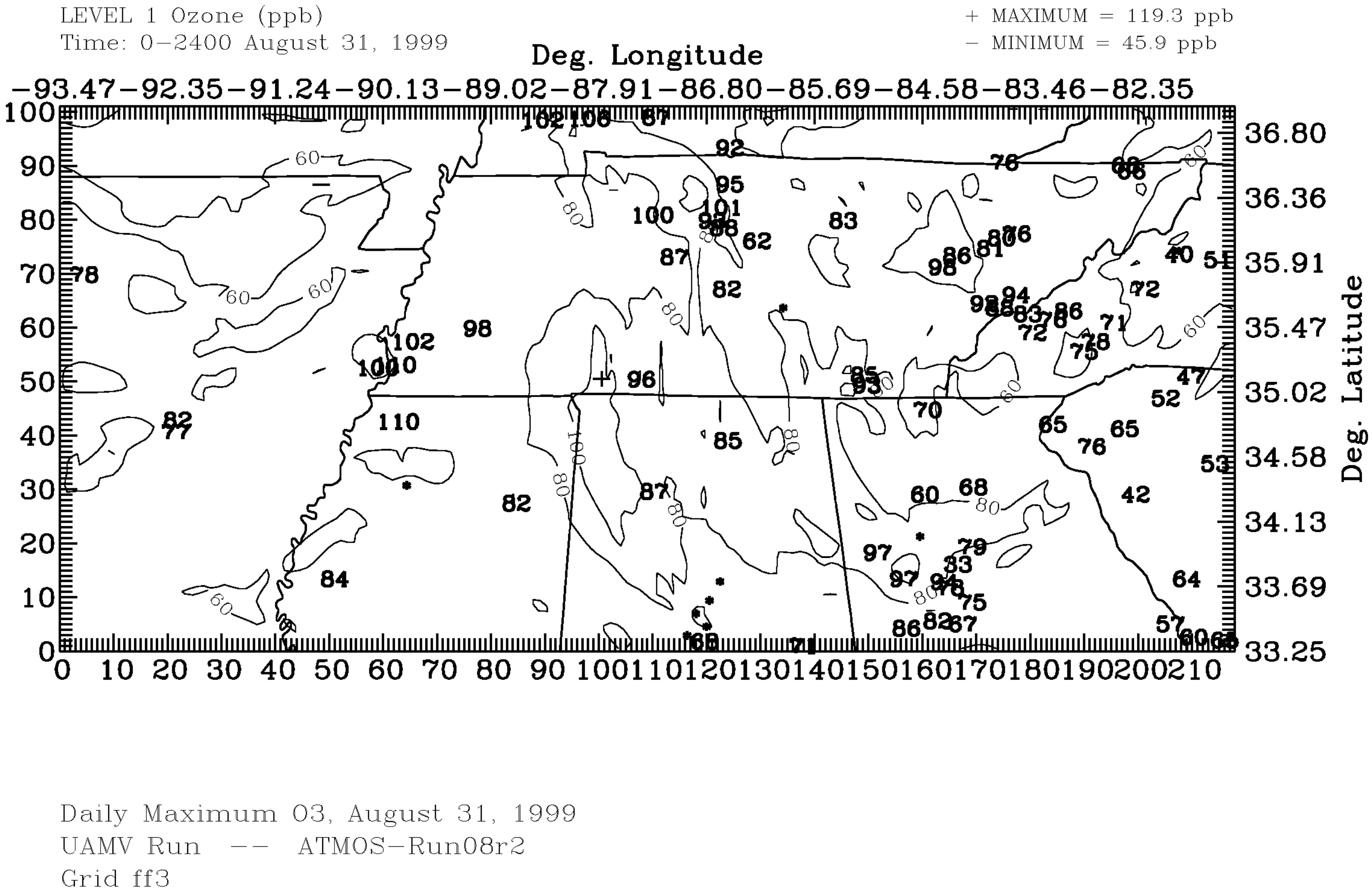


Figure 6-3d.
Daily Maximum 1-Hour Ozone, Grid 3,
September 1, 1999

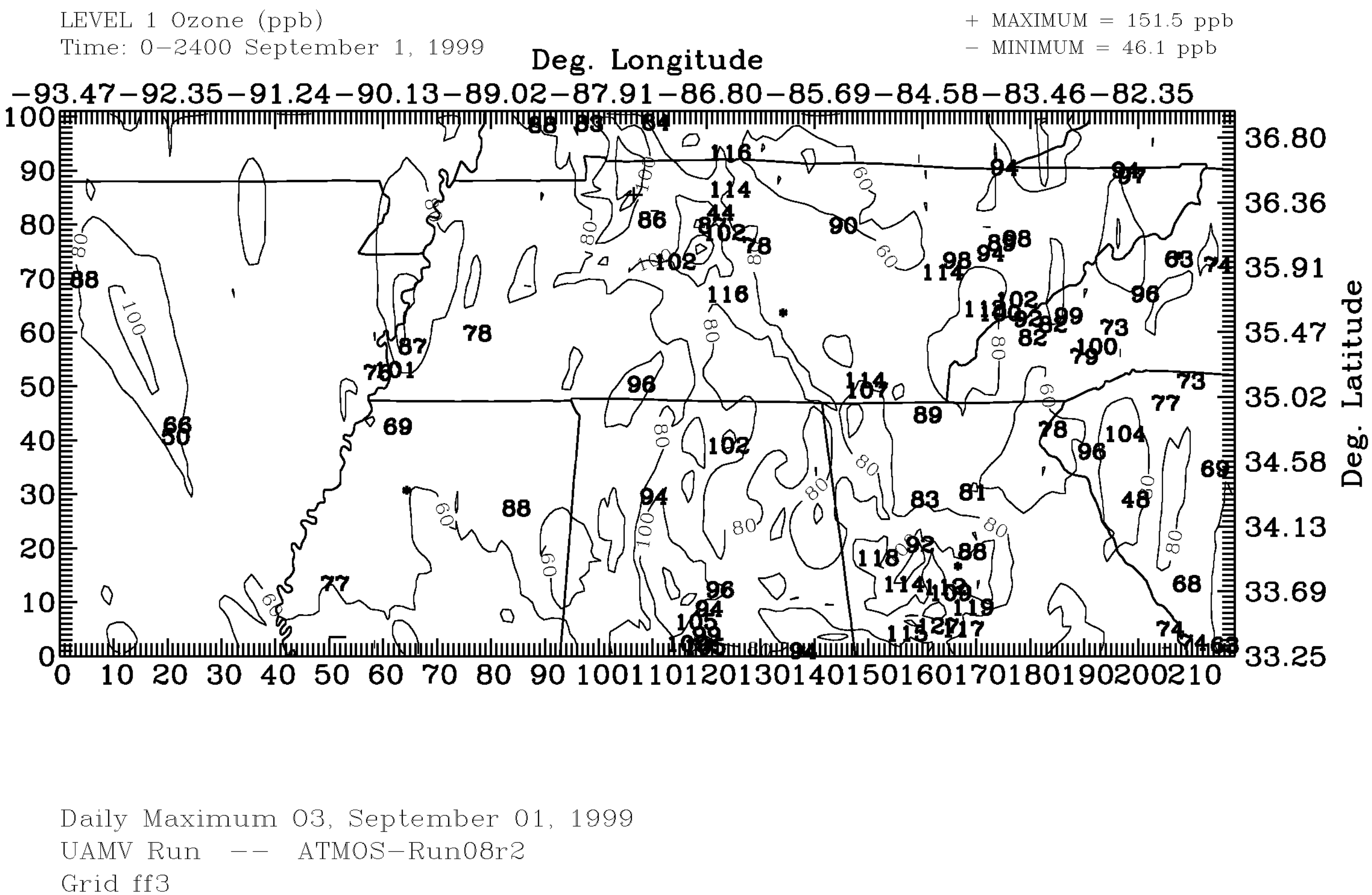
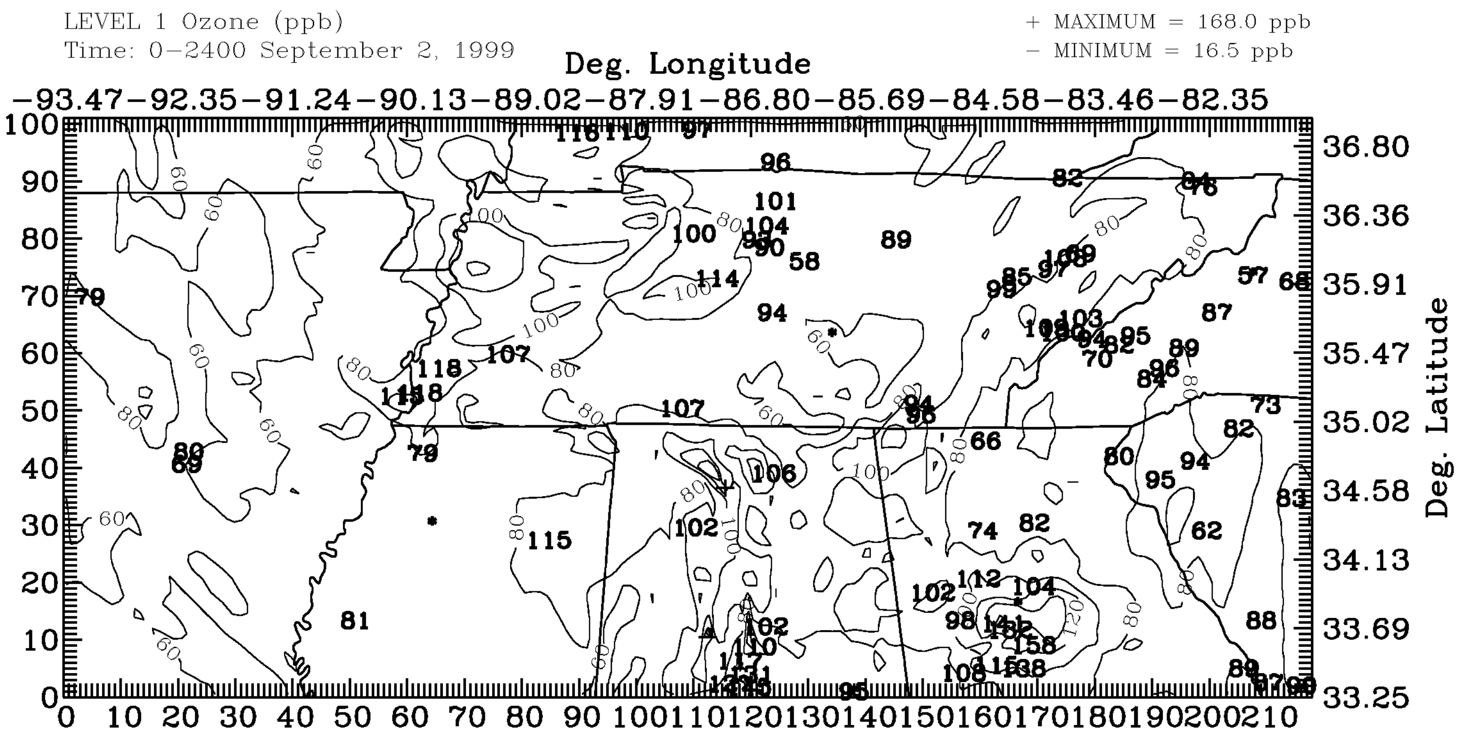


Figure 6-3e.
Daily Maximum 1-Hour Ozone, Grid 3,
September 2, 1999



Daily Maximum O3, September 02, 1999
UAMV Run -- ATMOS-Run08r2
Grid ff3

Figure 6-3f.
Daily Maximum 1-Hour Ozone, Grid 3,
September 3, 1999

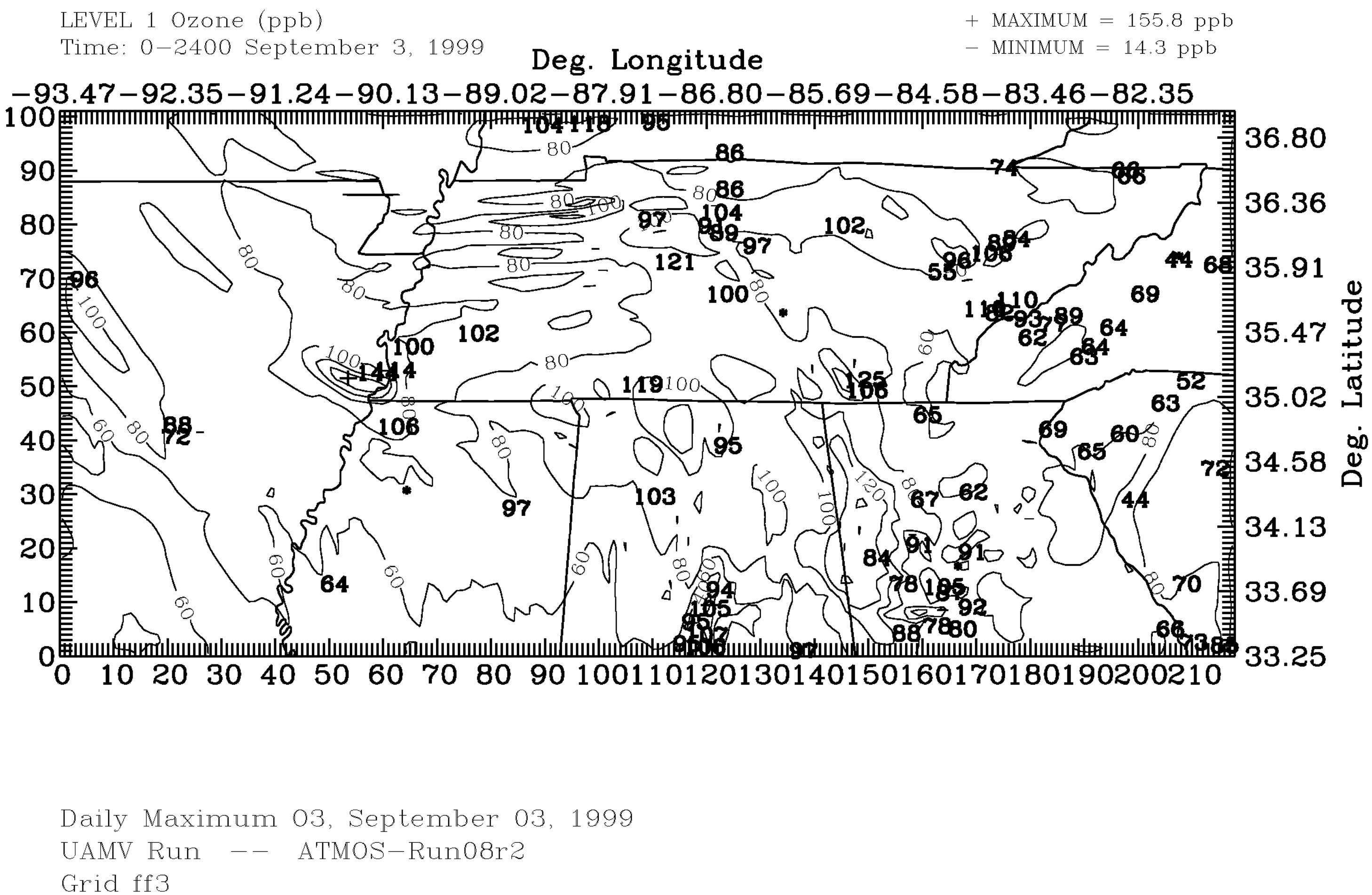


Figure 6-2g.
Daily Maximum 1-Hour Ozone, Grid 3,
September 4, 1999

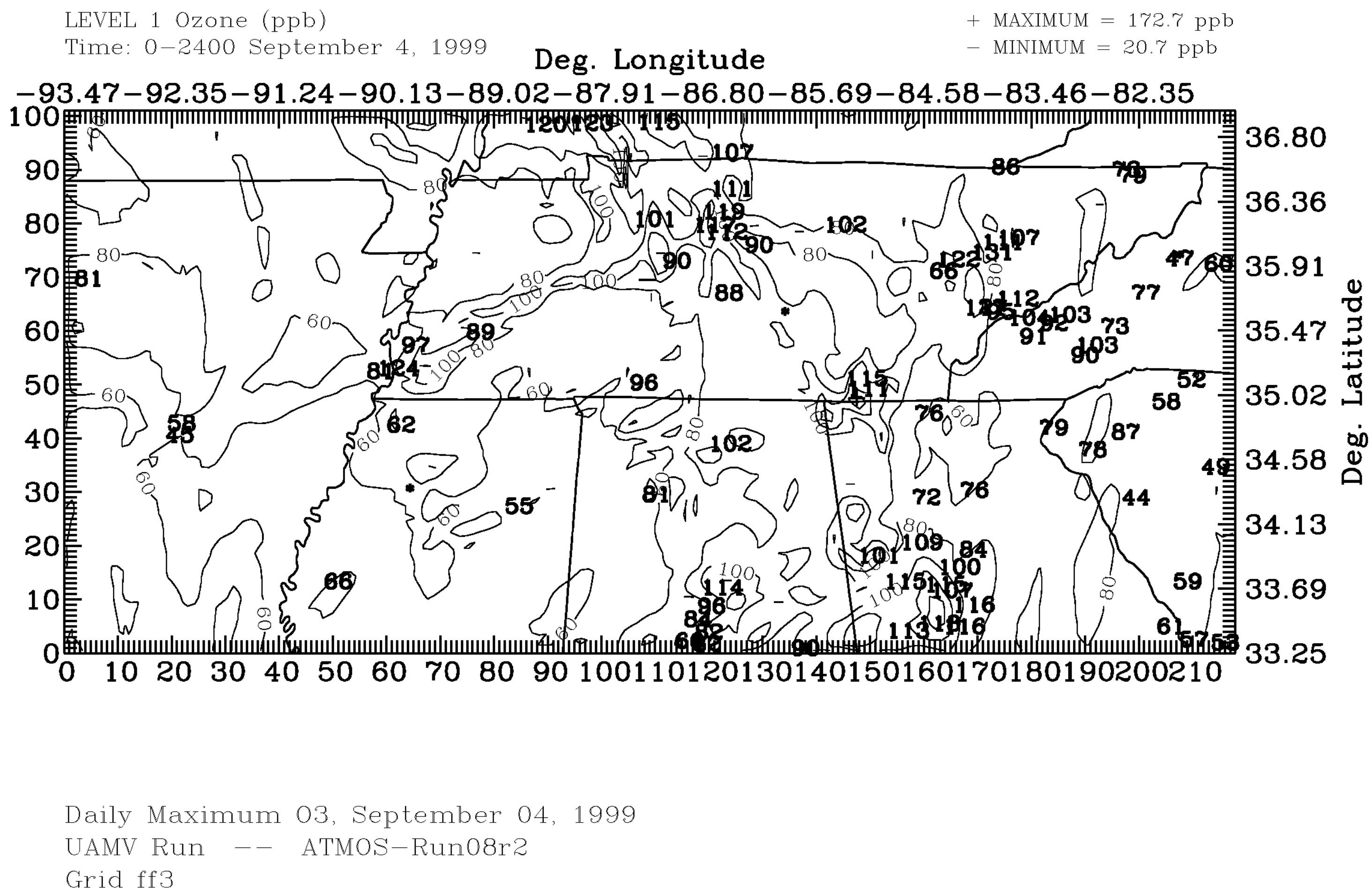


Figure 6-2h.
Daily Maximum 1-Hour Ozone, Grid 3,
September 5, 1999

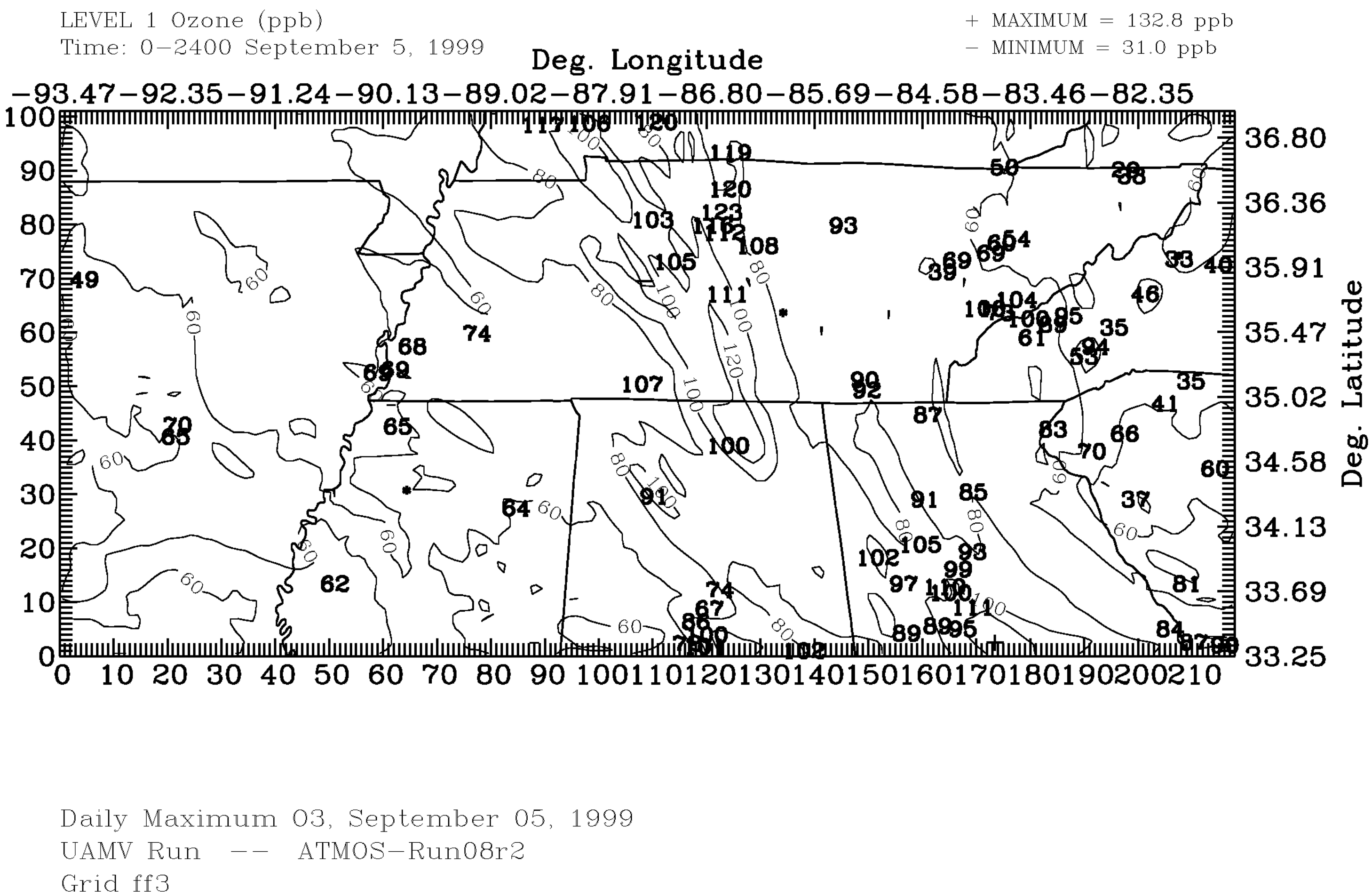


Figure 6-2i.
Daily Maximum 1-Hour Ozone, Grid 3,
September 6, 1999

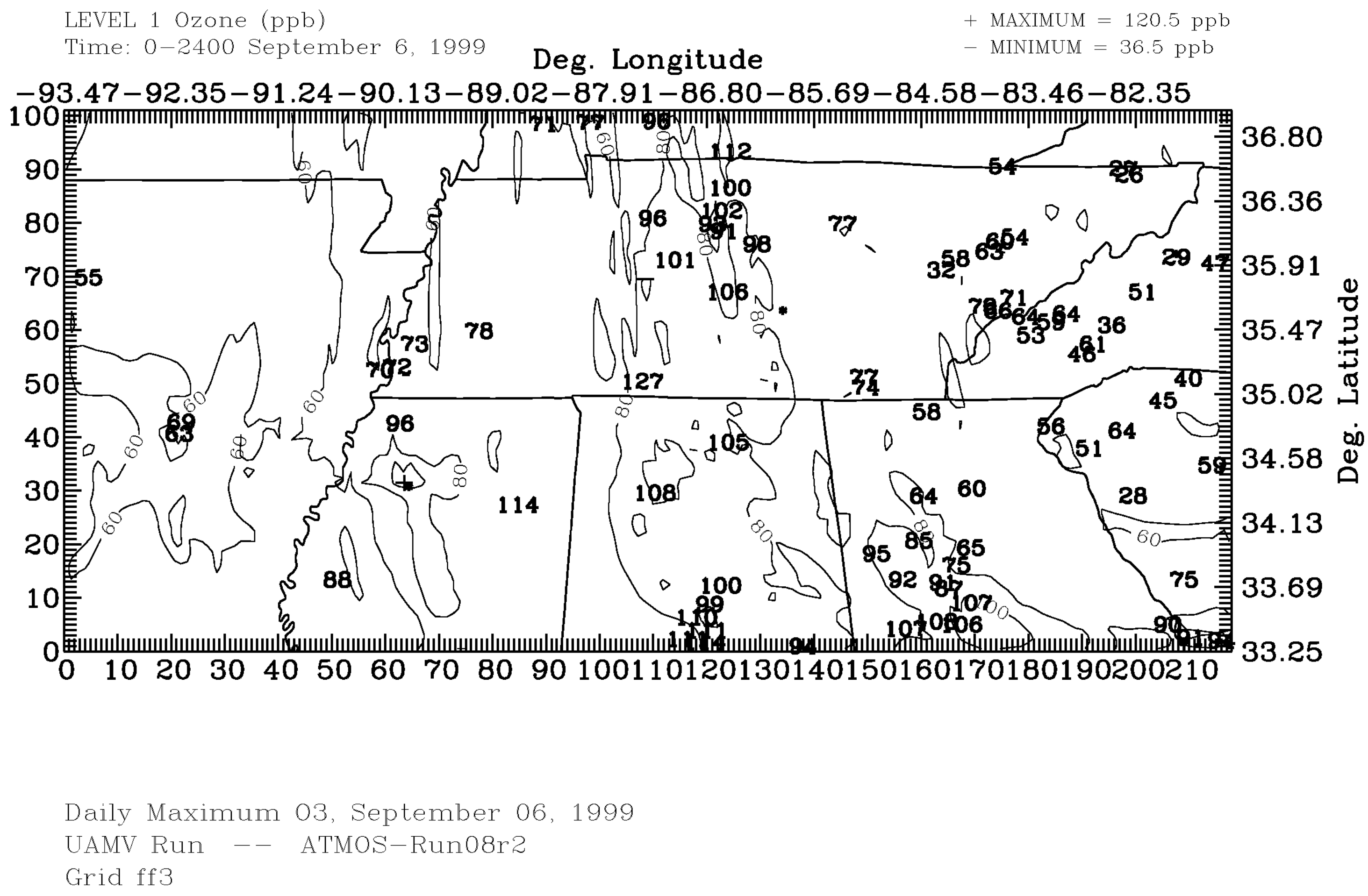


**Figure 6-2j.
Daily Maximum 1-Hour Ozone, Grid 3,
September 7, 1999**

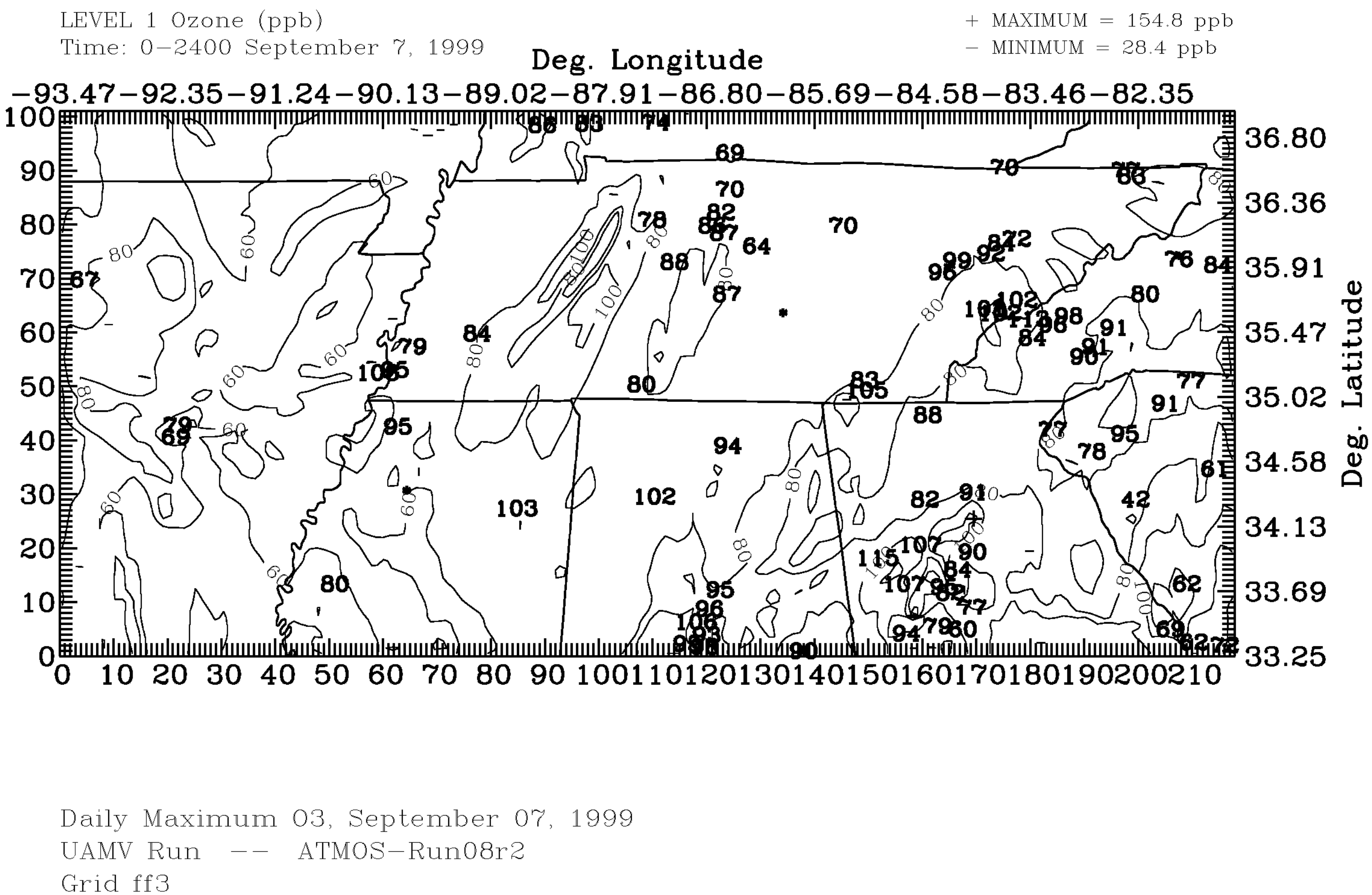


Figure 6-2k.
Daily Maximum 1-Hour Ozone, Grid 3,
September 8, 1999

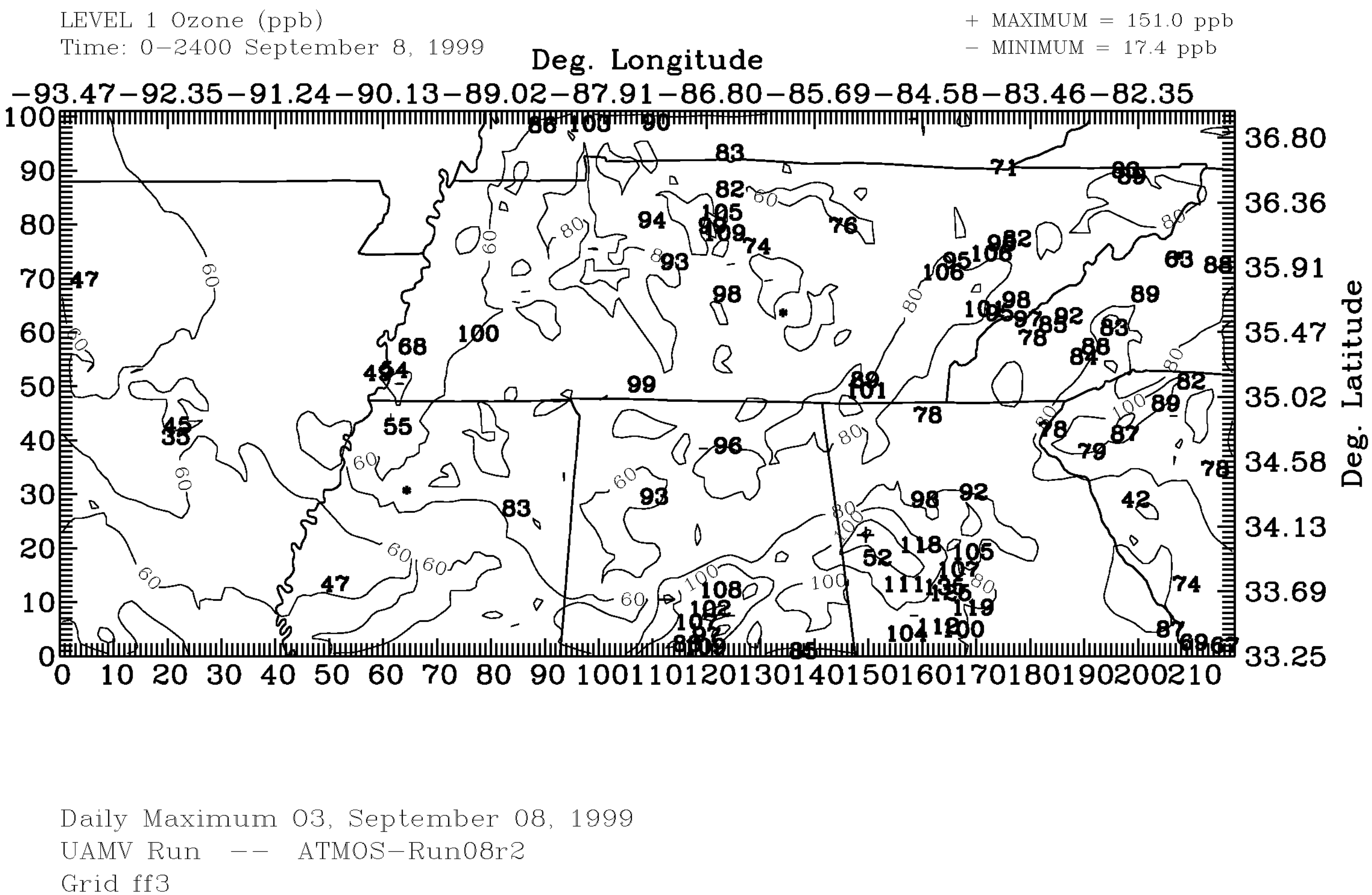


Figure 6-2l.
Daily Maximum 1-Hour Ozone, Grid 3,
September 9, 1999

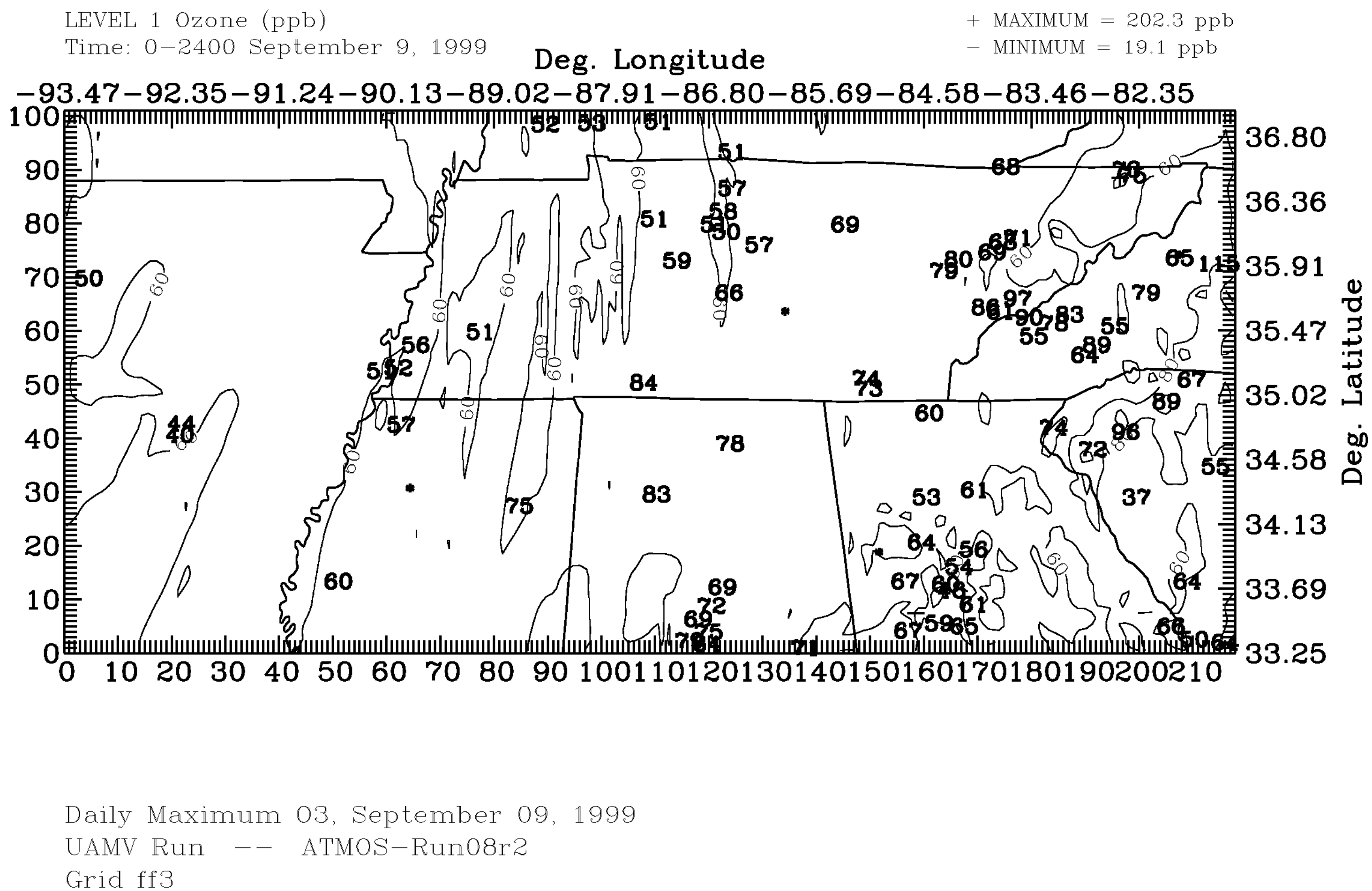


Figure 6-3a.
1999 Episode Time Series: Memphis EAC Area,
August 29 to September 3, 1999

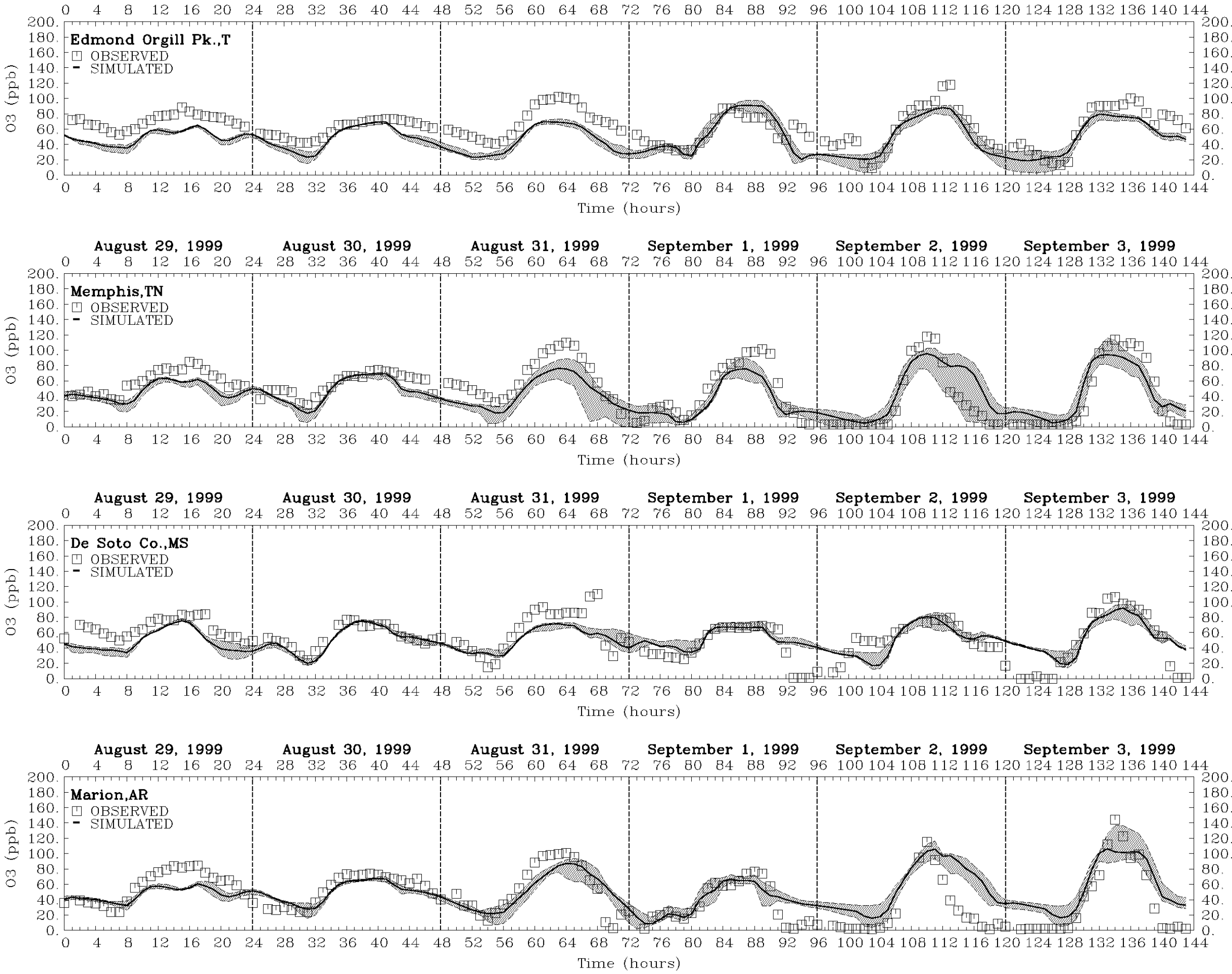


Figure 6-3b.
1999 Episode Time Series: Memphis EAC Area,
September 4-9, 1999

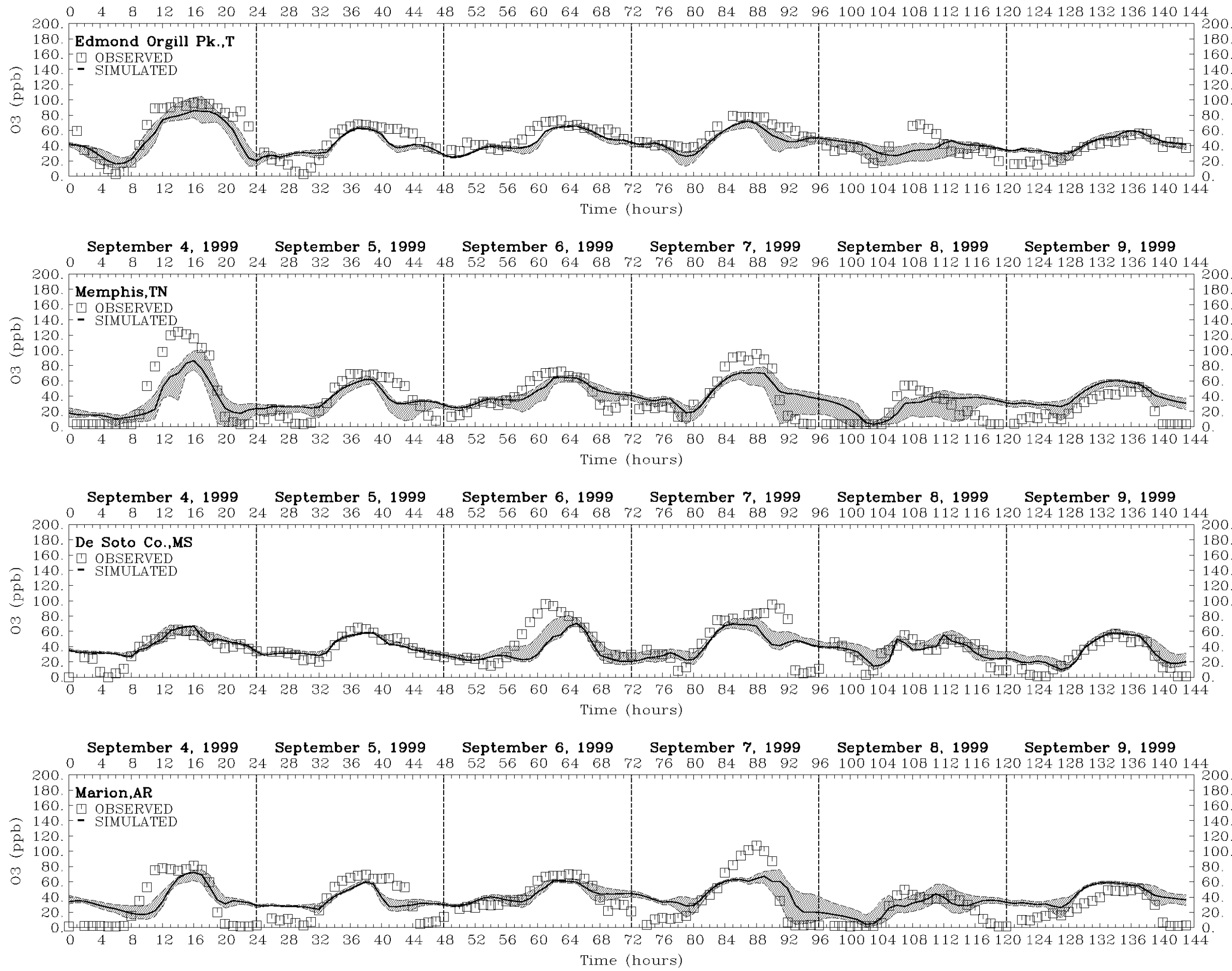


Figure 6-3c.
1999 Episode Time Series: Nashville EAC Area,
August 29 to September 3, 1999

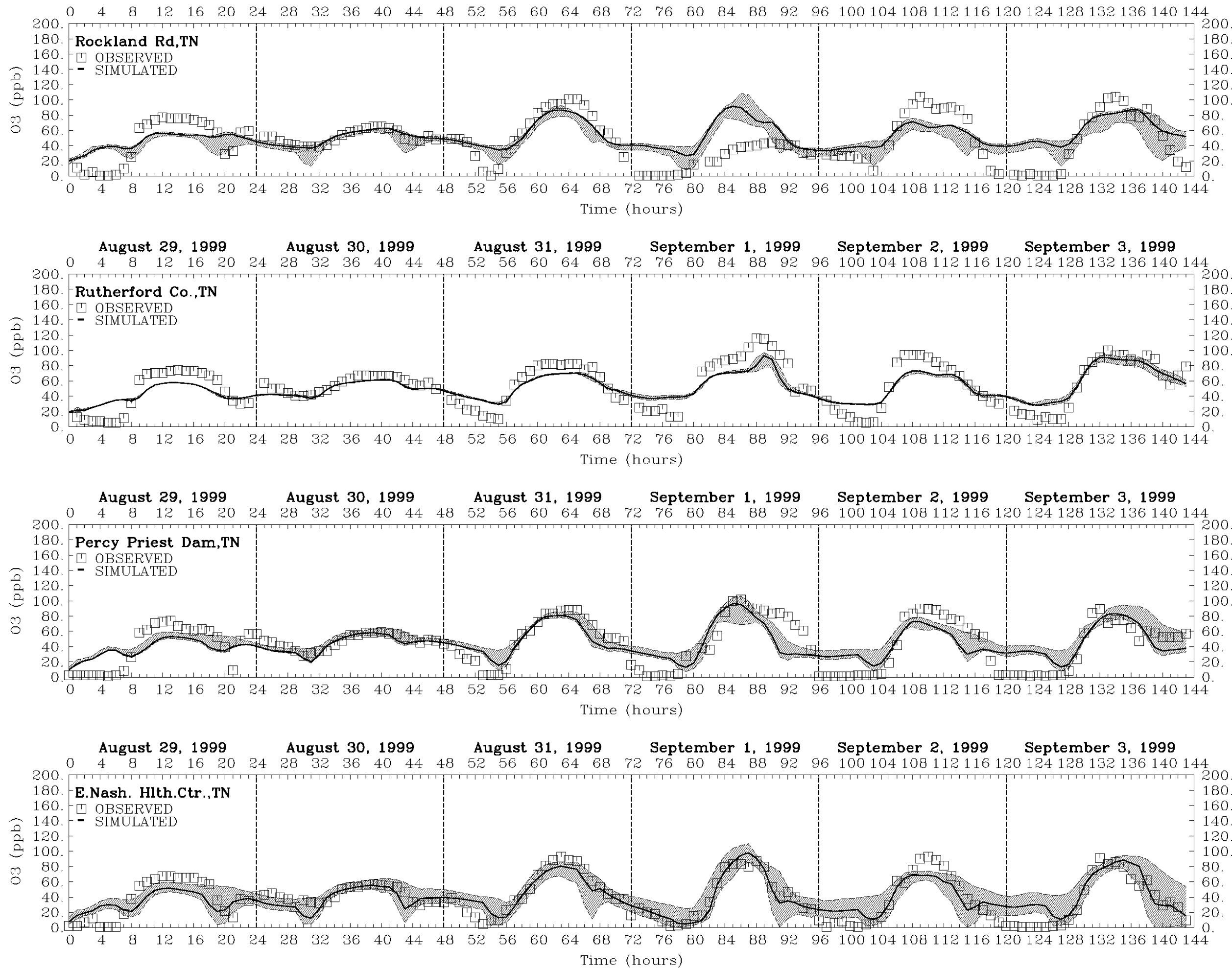


Figure 6-3d.
1999 Episode Time Series: Nashville EAC Area *(continued)*,
August 29 to September 3, 1999

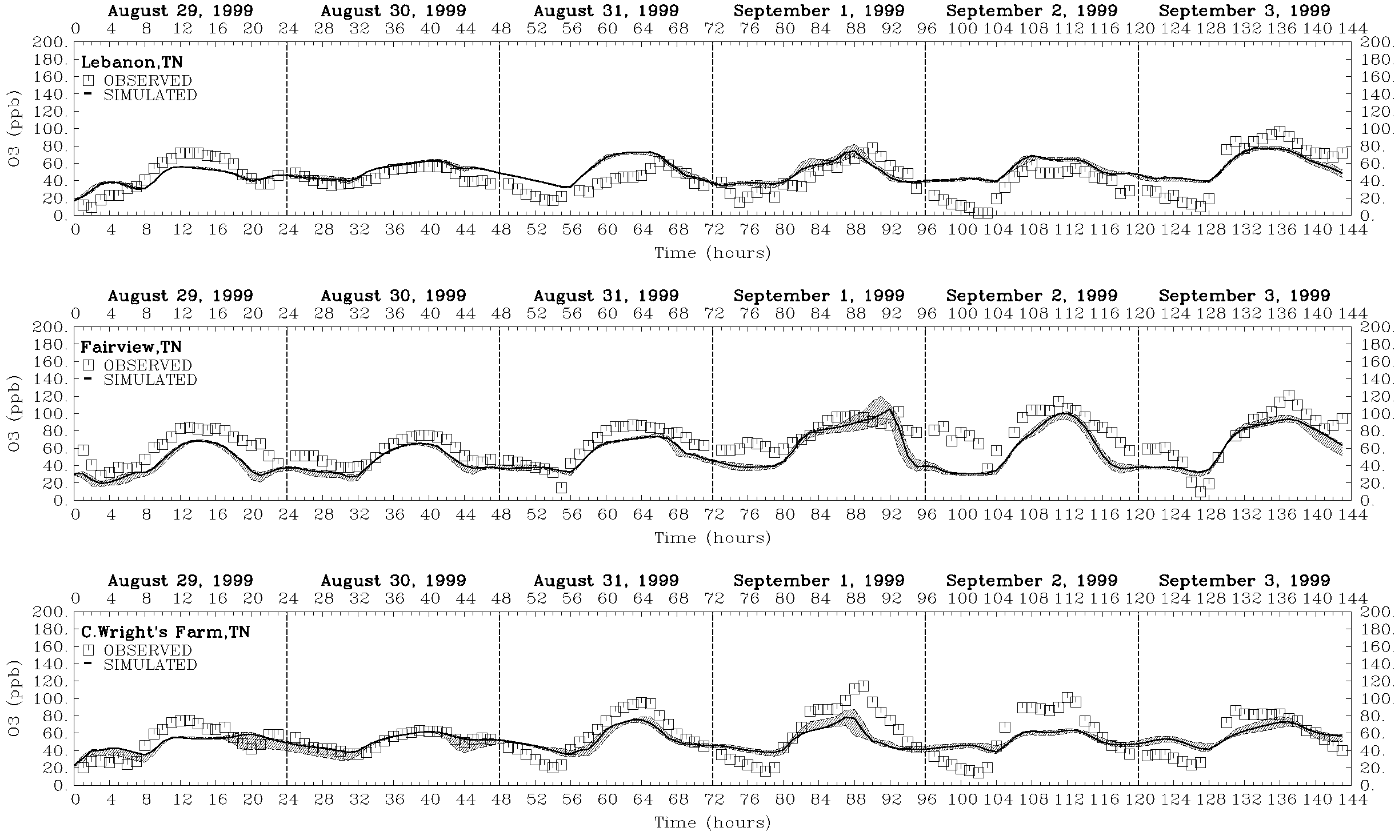


Figure 6-3e.
1999 Episode Time Series: Nashville EAC Area,
September 4-9, 1999

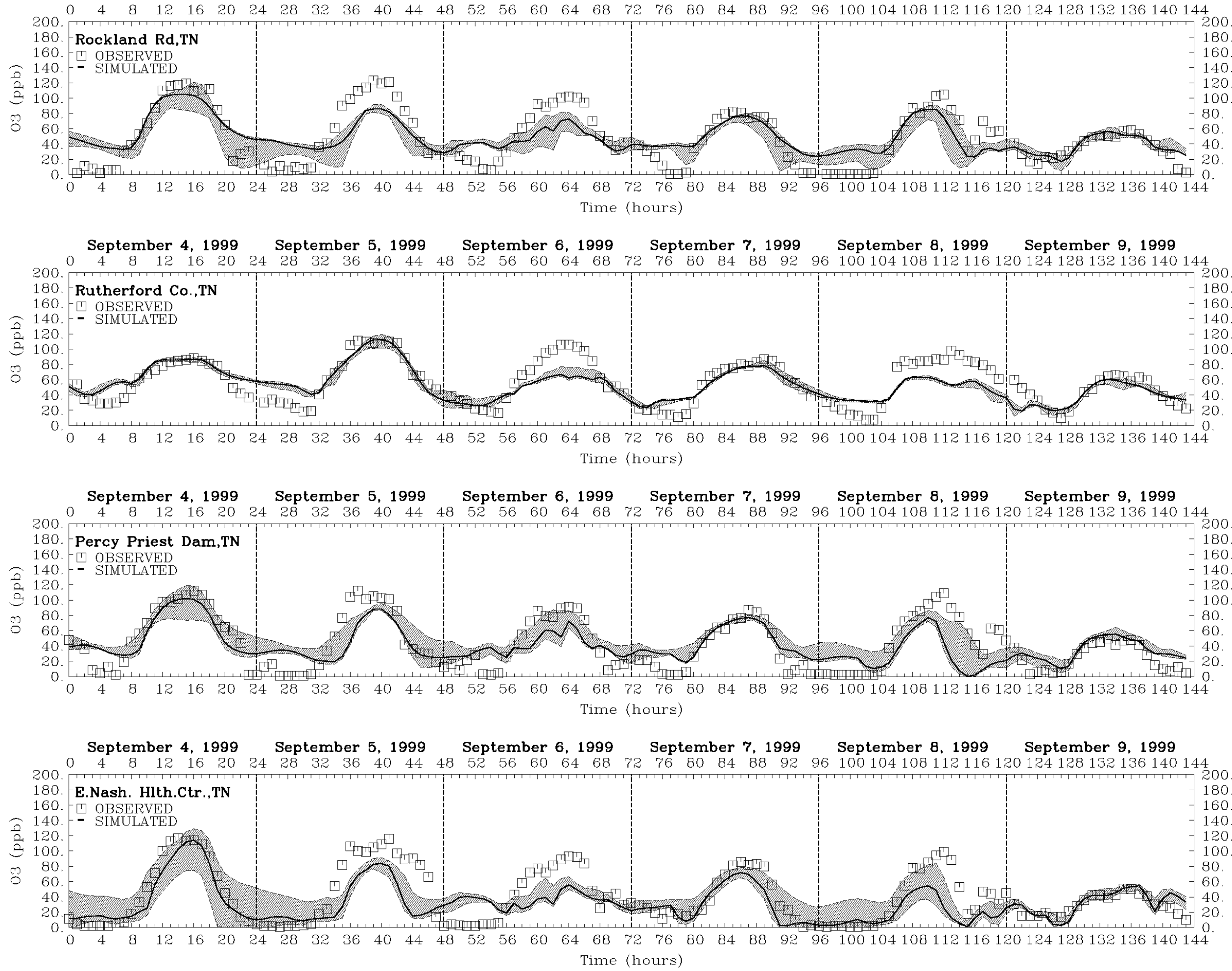


Figure 6-3f.
1999 Episode Time Series: Nashville EAC Area *(continued)*,
September 4–9, 1999

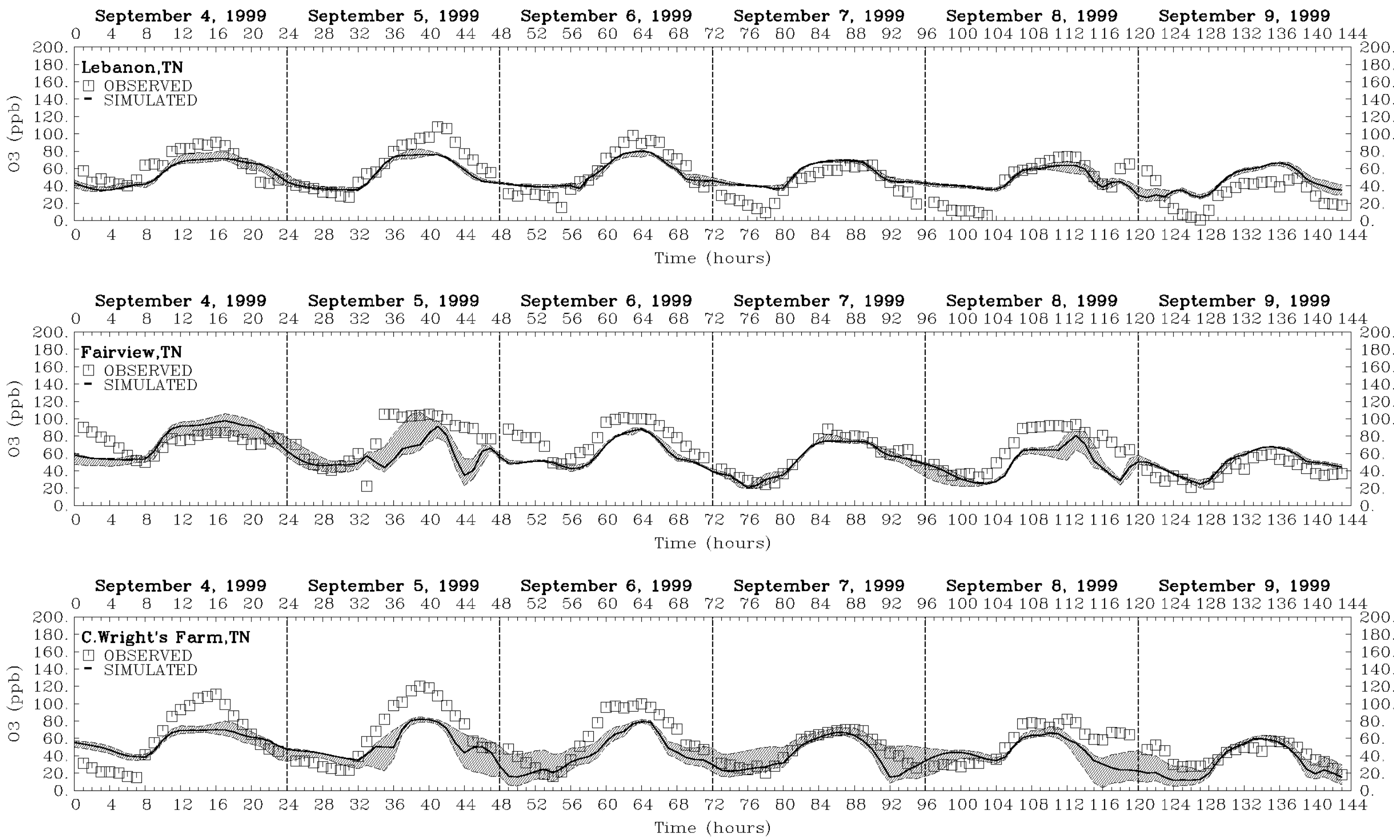


Figure 6-3g.
1999 Episode Time Series: Knoxville EAC Area,
August 29 to September 3, 1999

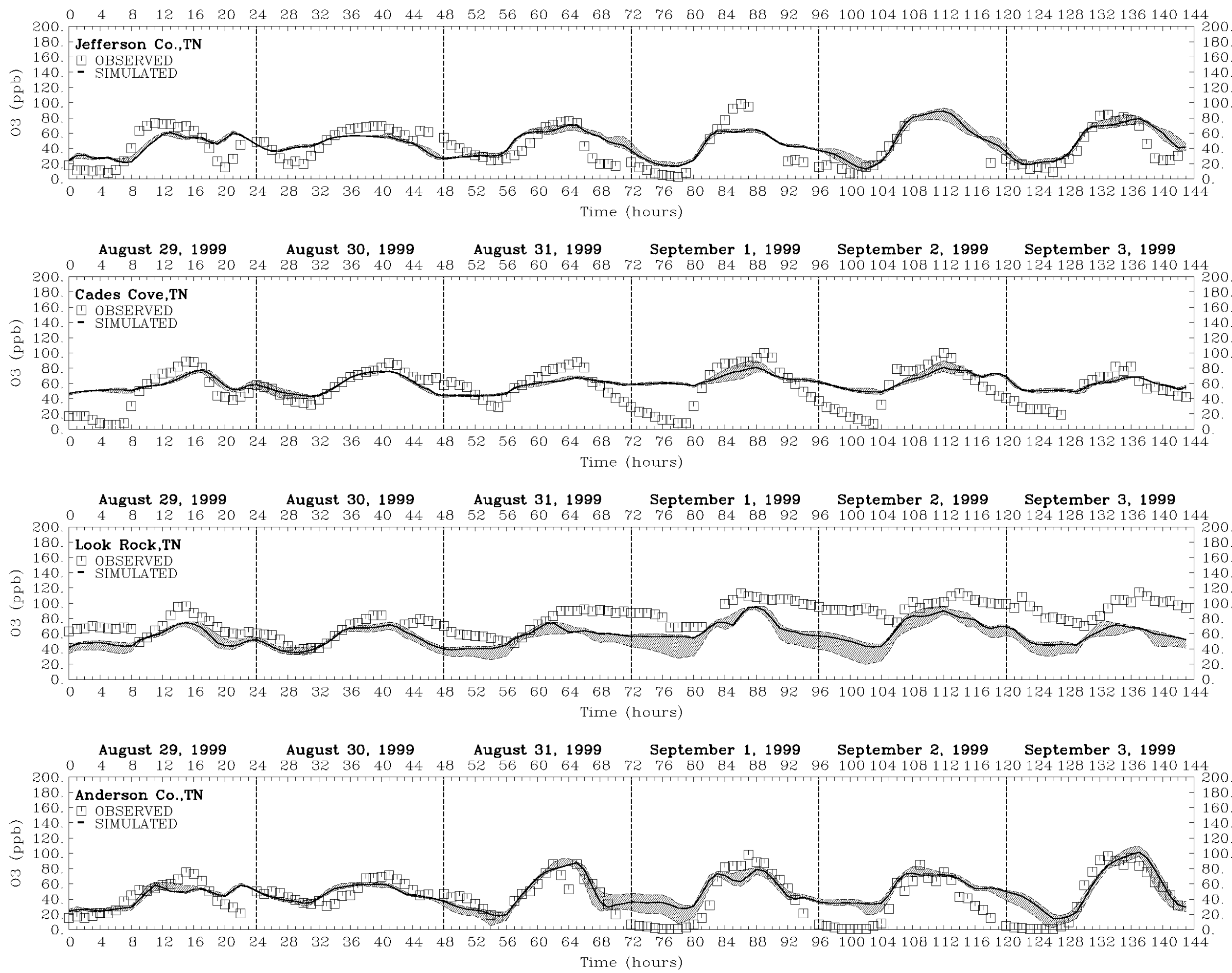


Figure 6-3h.
1999 Episode Time Series: Knoxville EAC Area *(continued)*,
August 29 to September 3, 1999

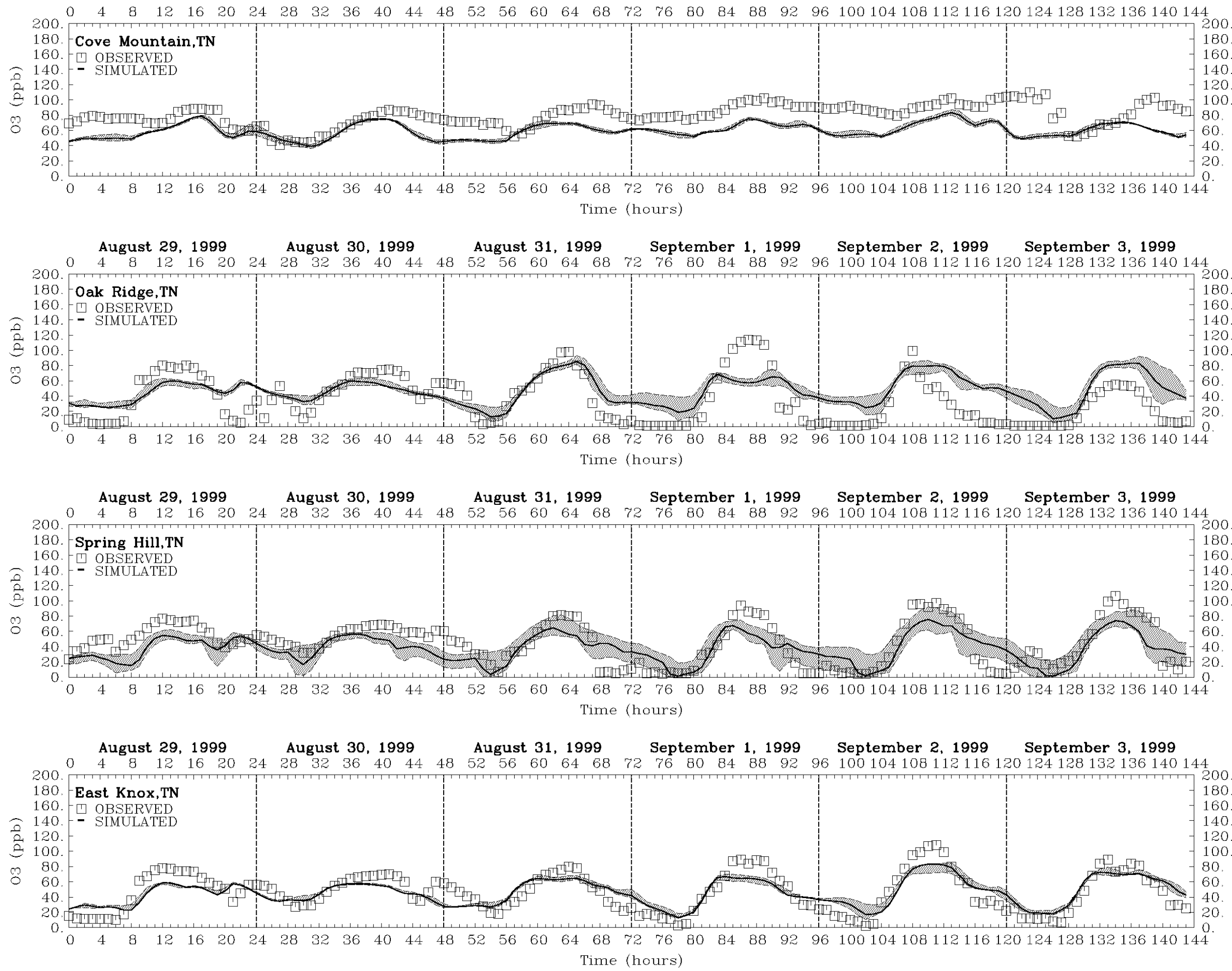


Figure 6-3i.
1999 Episode Time Series: Knoxville EAC Area,
September 4-9, 1999

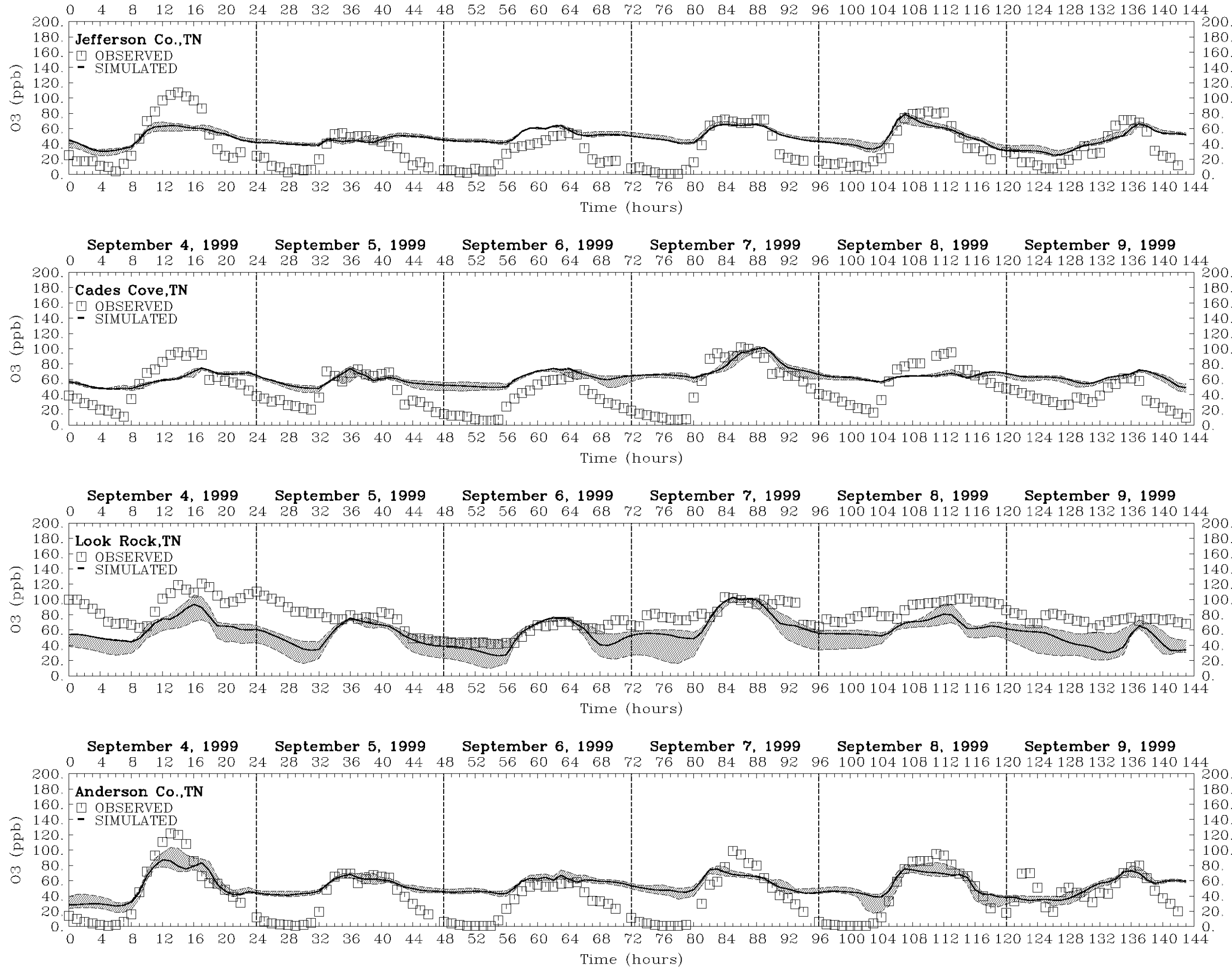
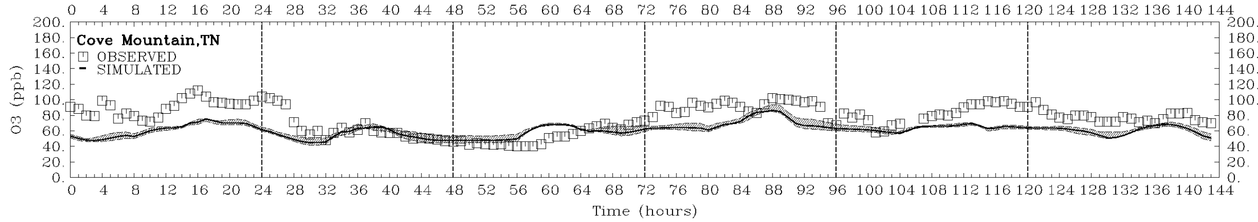
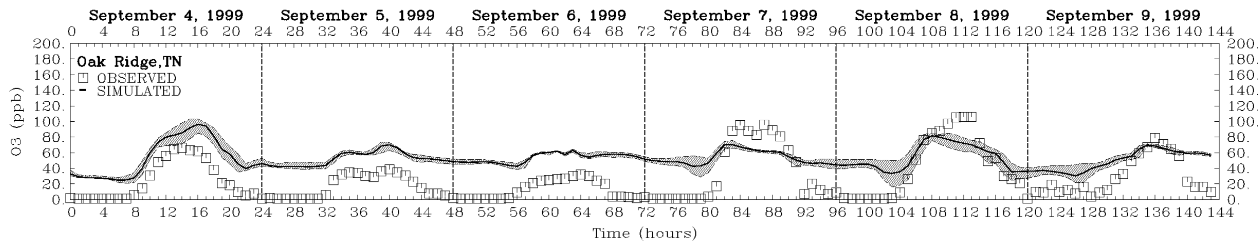
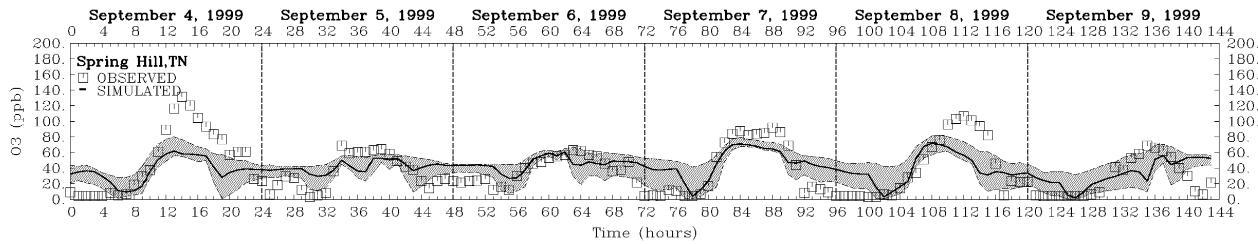


Figure 6-3j.
1999 Episode Time Series: Knoxville EAC Area *(continued)*,
September 4-9, 1999







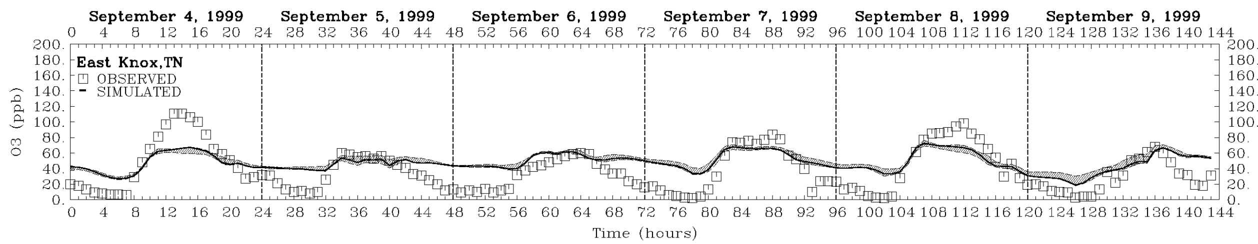
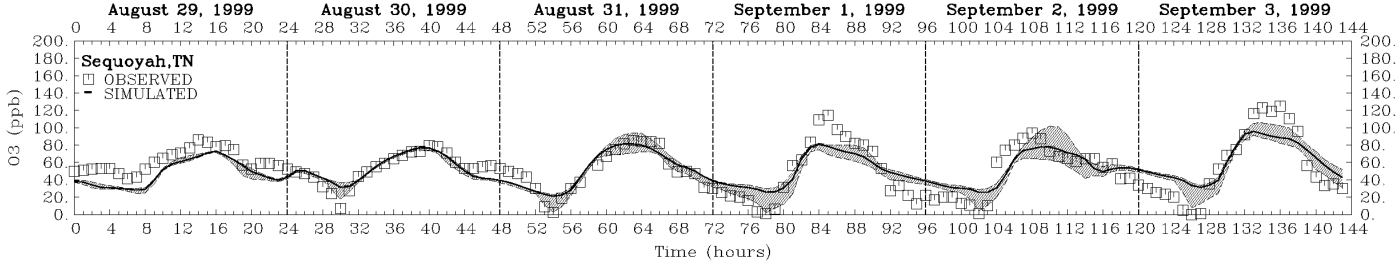


Figure 6-3k.
1999 Episode Time Series: Chattanooga EAC Area,
August 29 to September 3, 1999



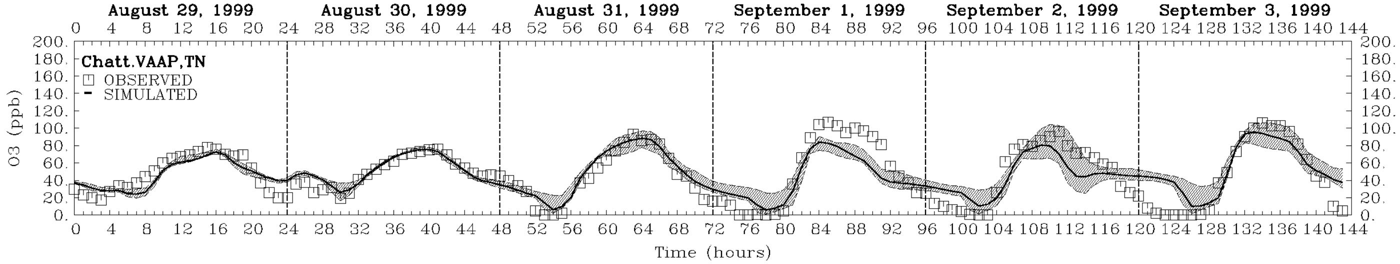


Figure 6-3l.
1999 Episode Time Series: Chattanooga EAC Area,
September 4-9, 1999

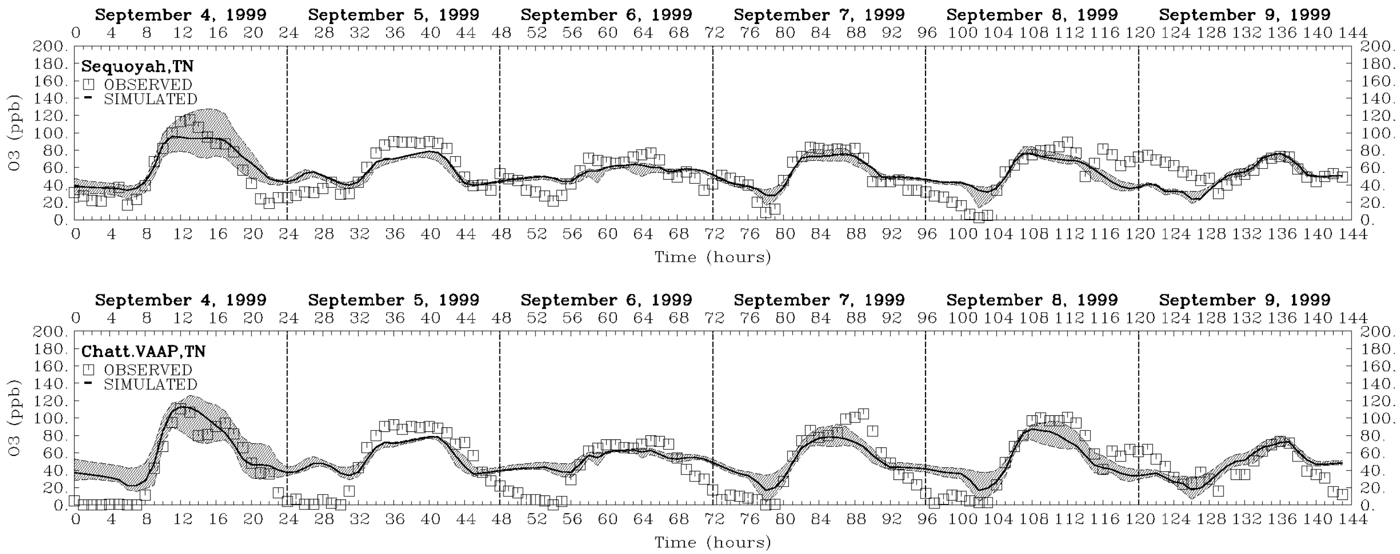


Figure 6-3m.
1999 Episode Time Series: Tri-Cities EAC Area,
August 29 to September 3, 1999

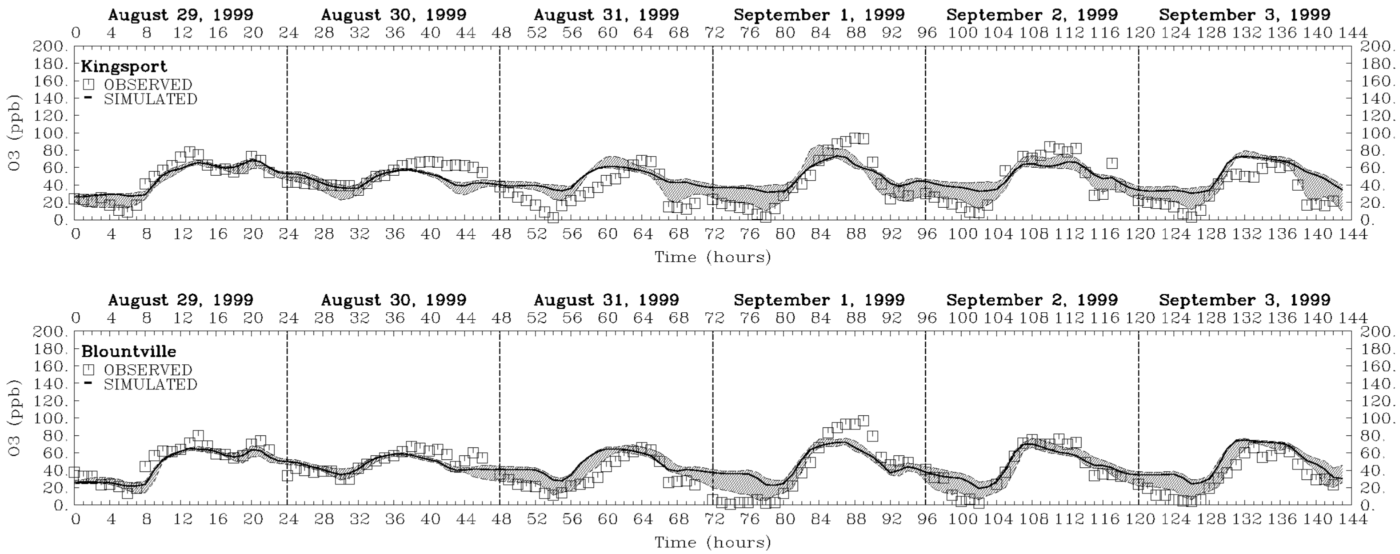


Figure 6-3n.
1999 Episode Time Series: Tri-Cities EAC Area,
September 4-9, 1999

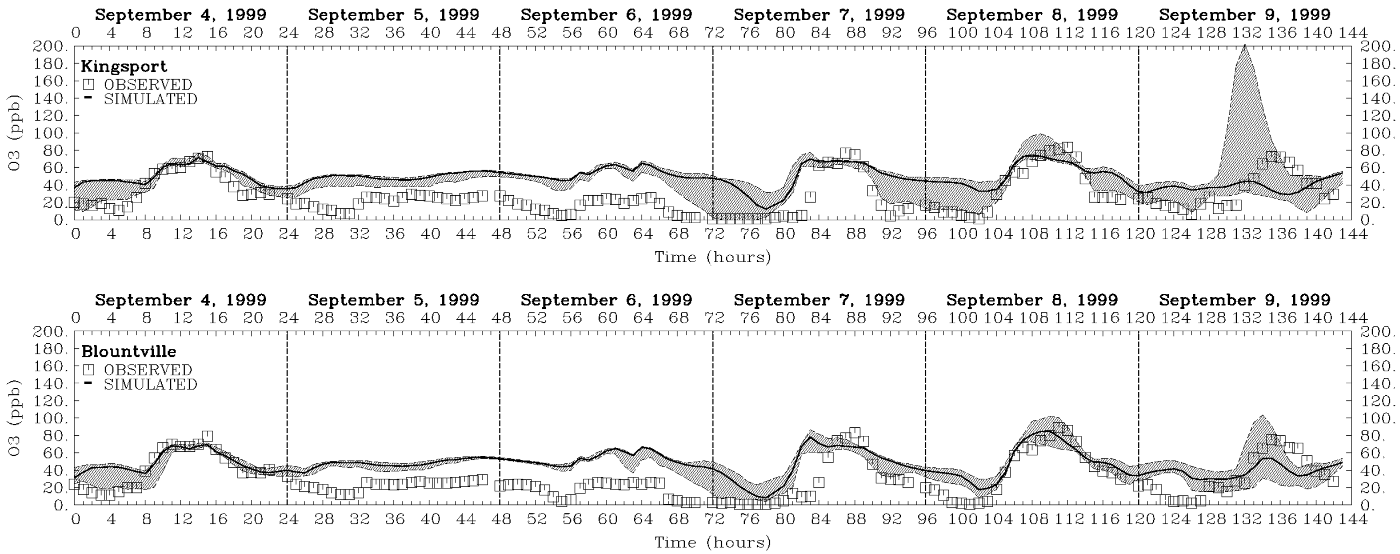
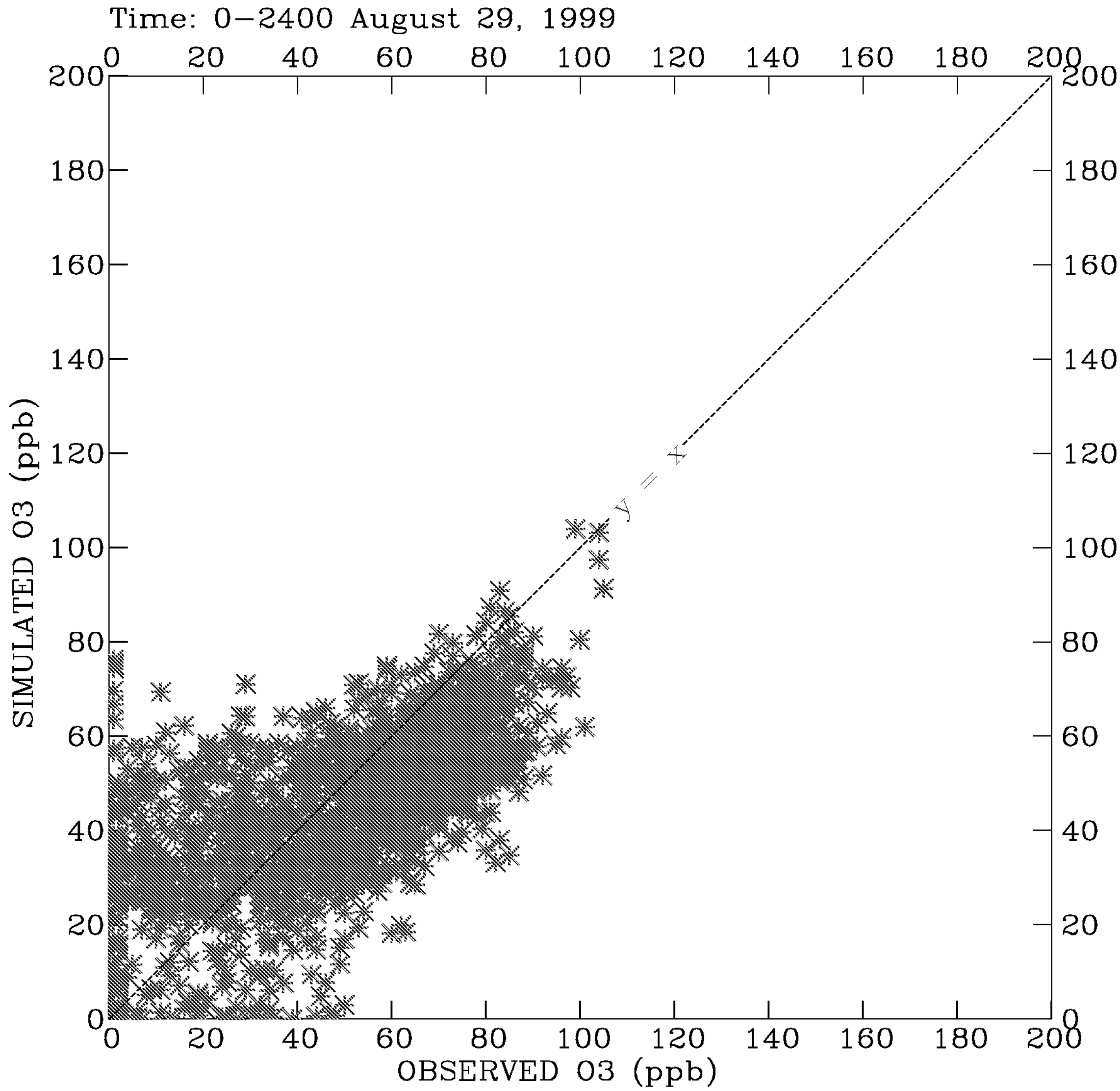
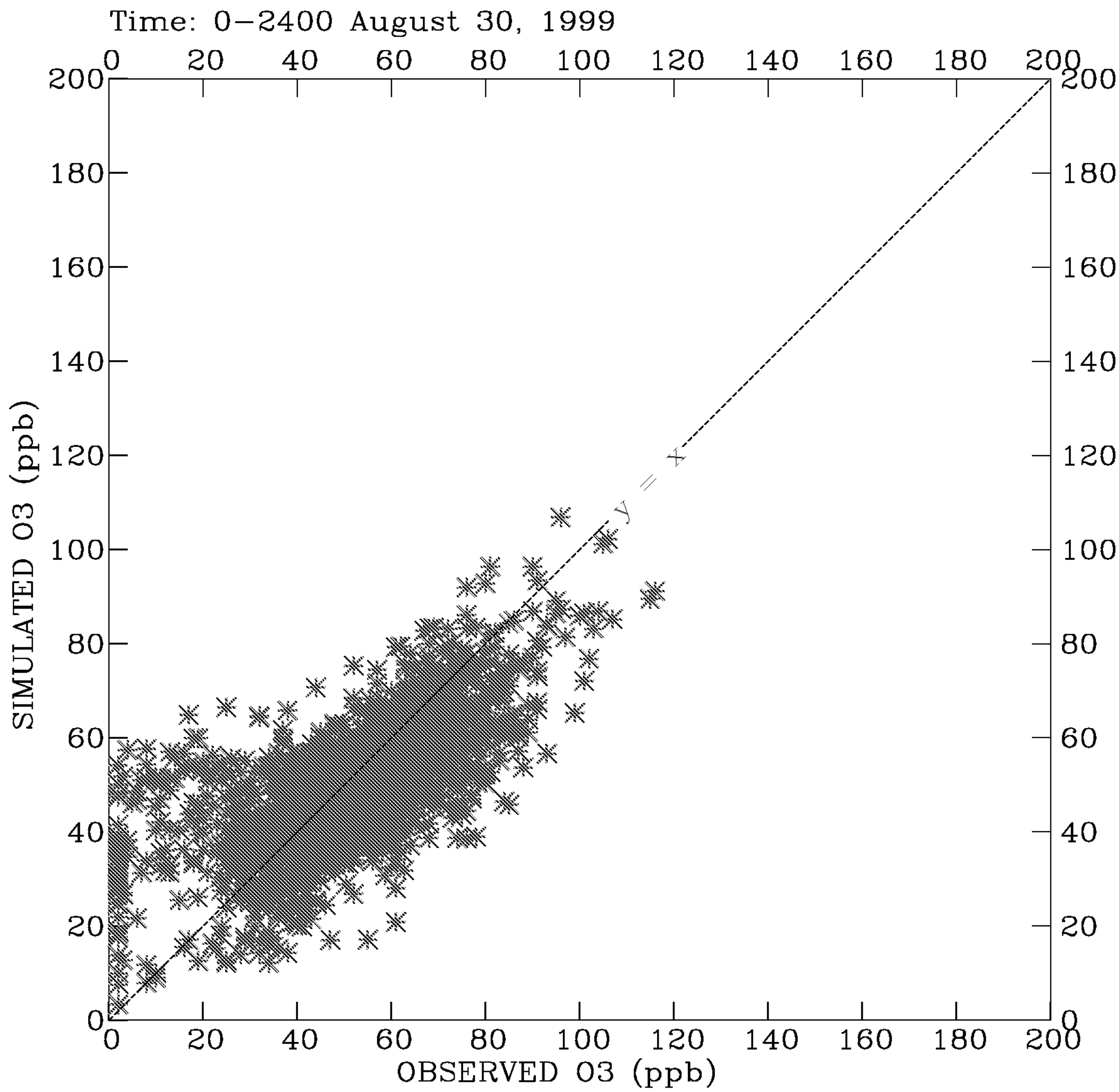


Figure 6-4a.
Scatter Plot: August 29, 1999



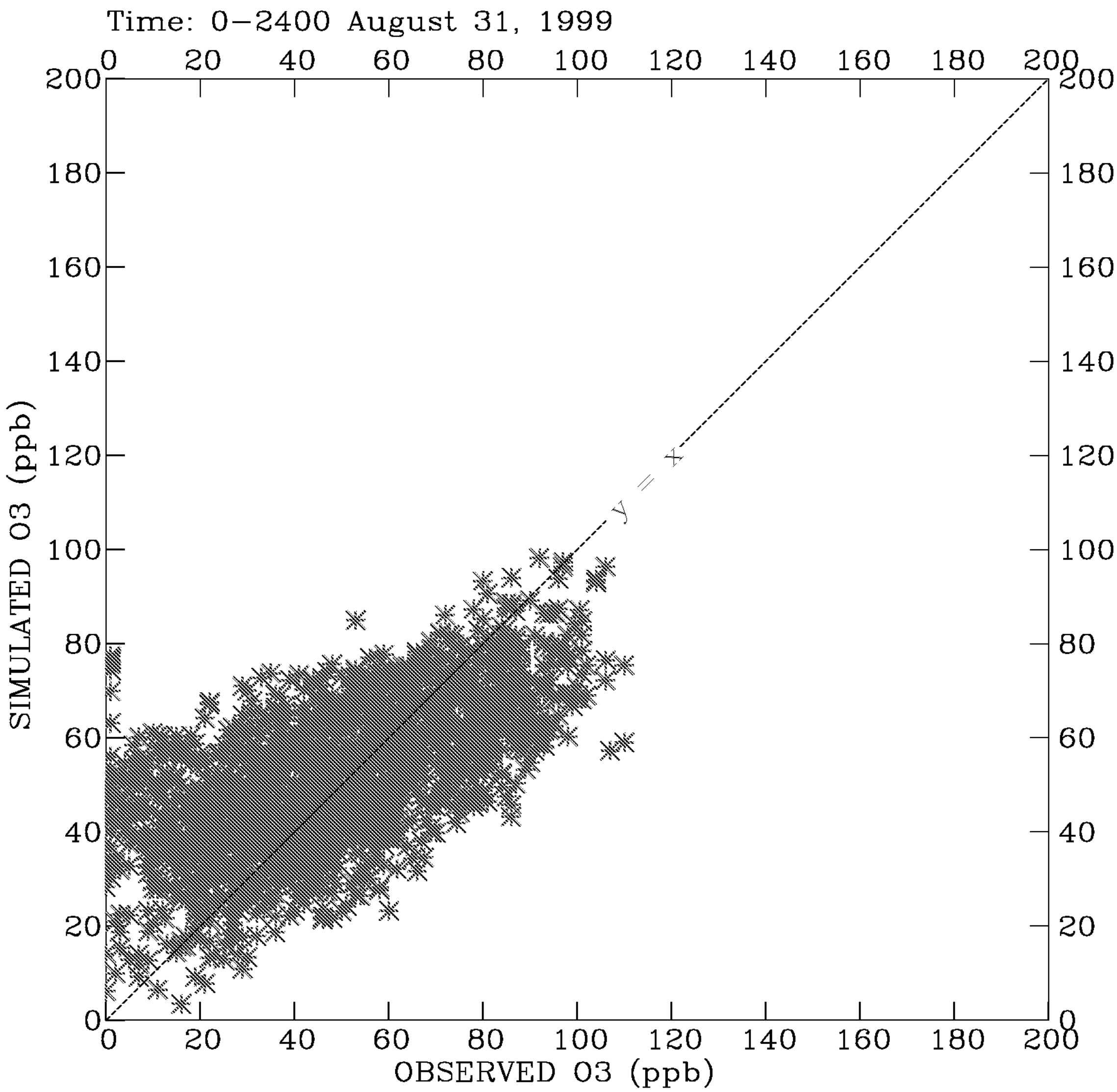
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4b.
Scatter Plot: August 30, 1999



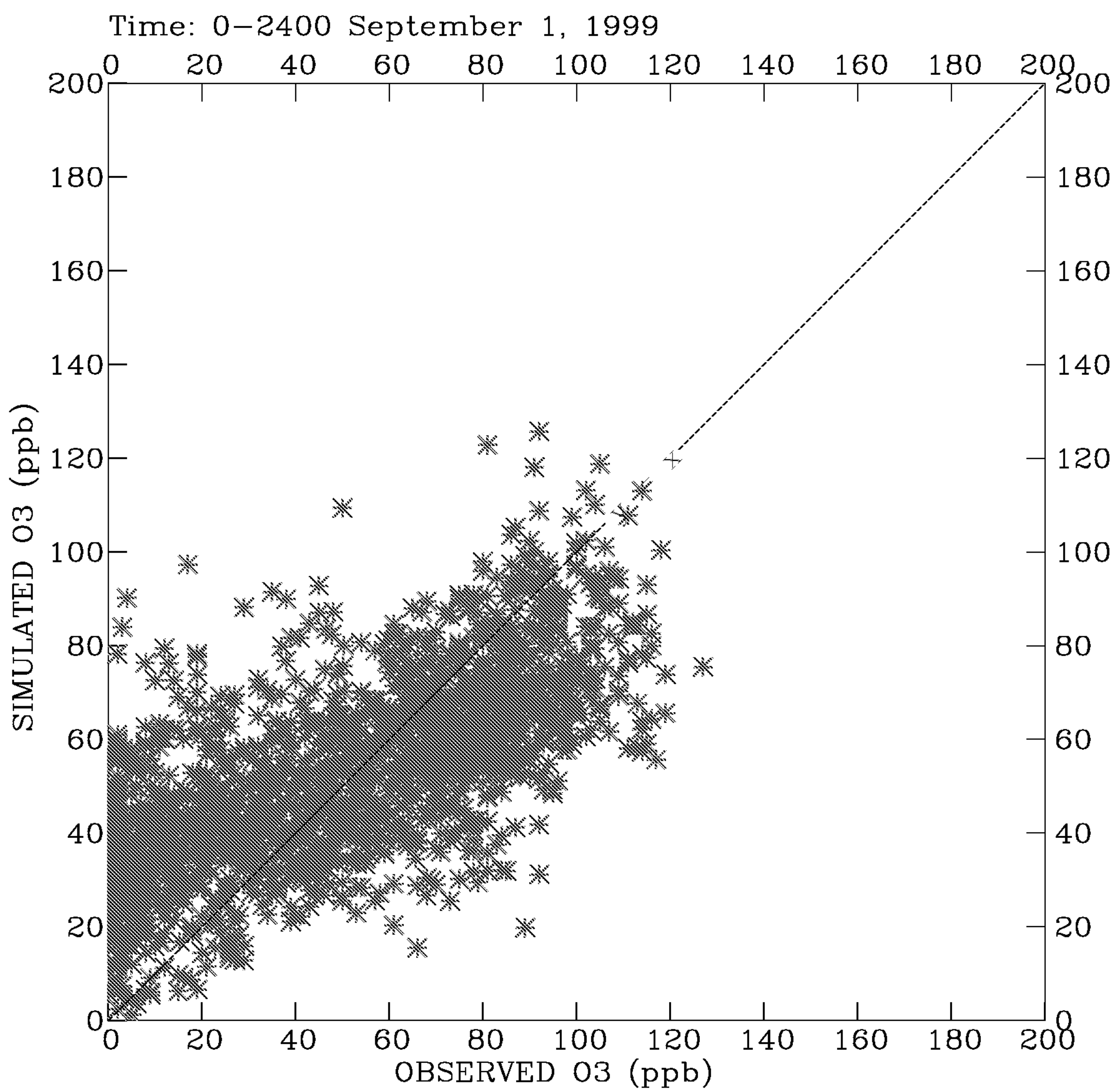
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4c.
Scatter Plot: August 31, 1999



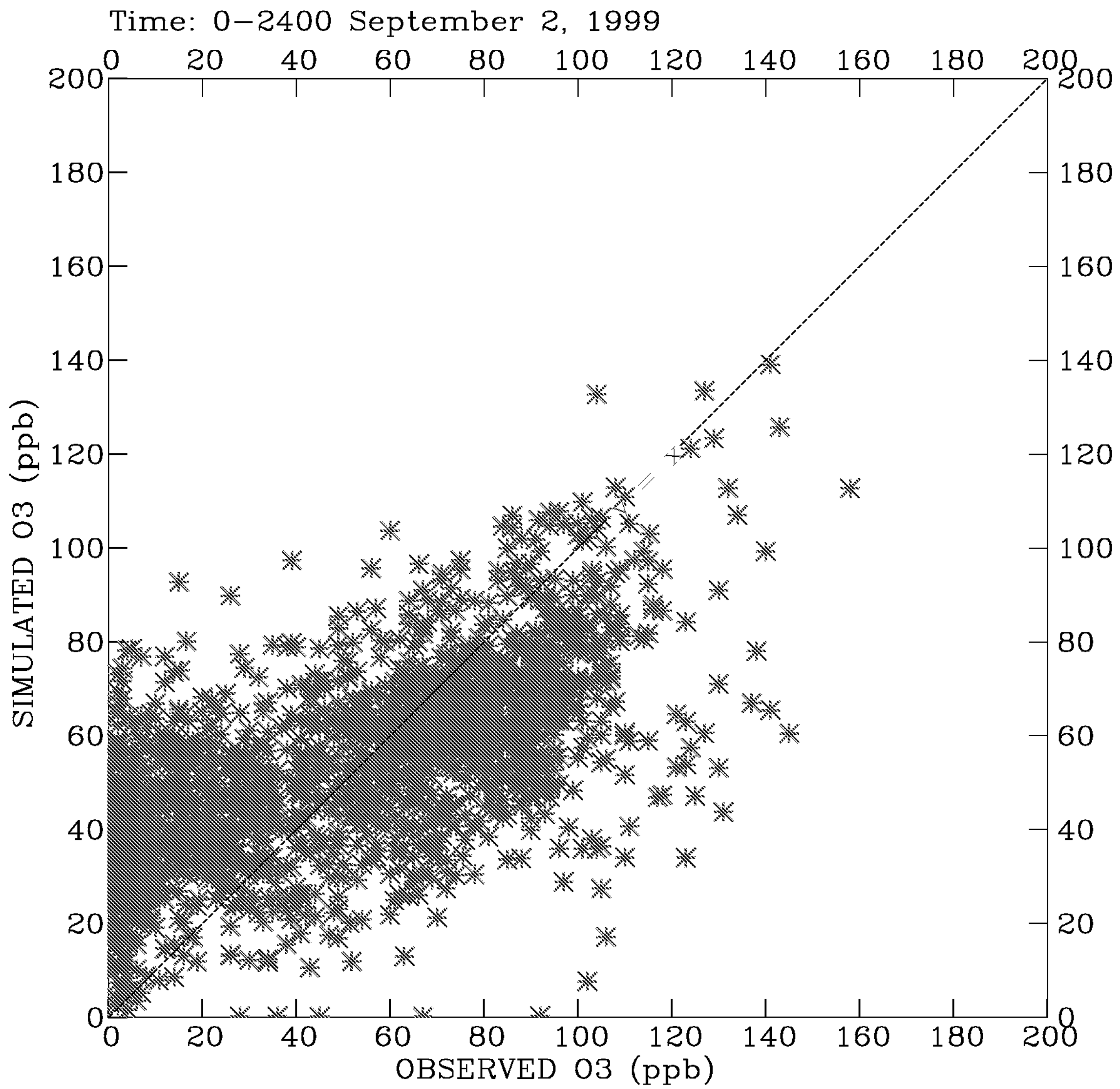
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4d.
Scatter Plot: September 1, 1999



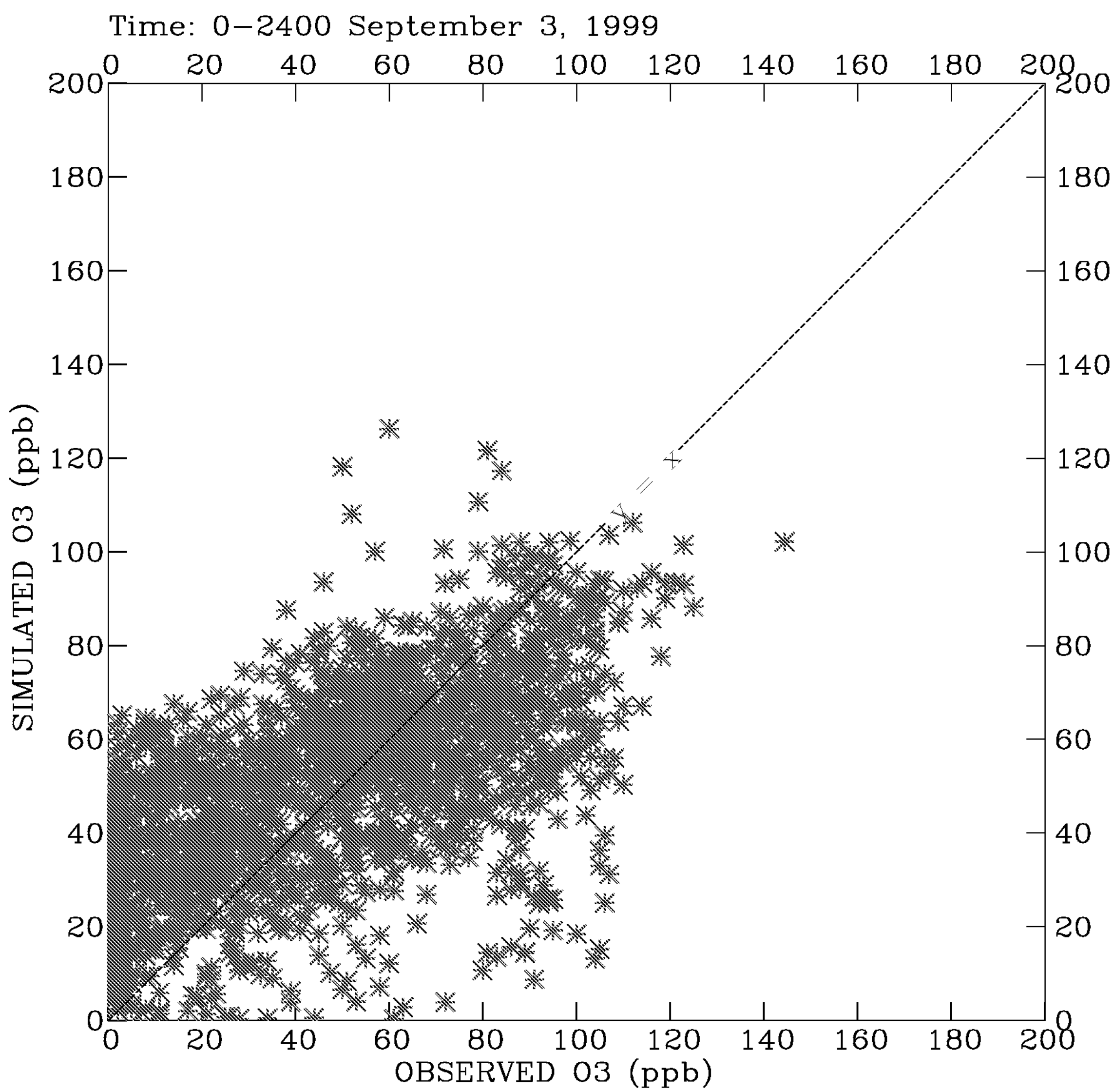
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4e.
Scatter Plot: September 2, 1999



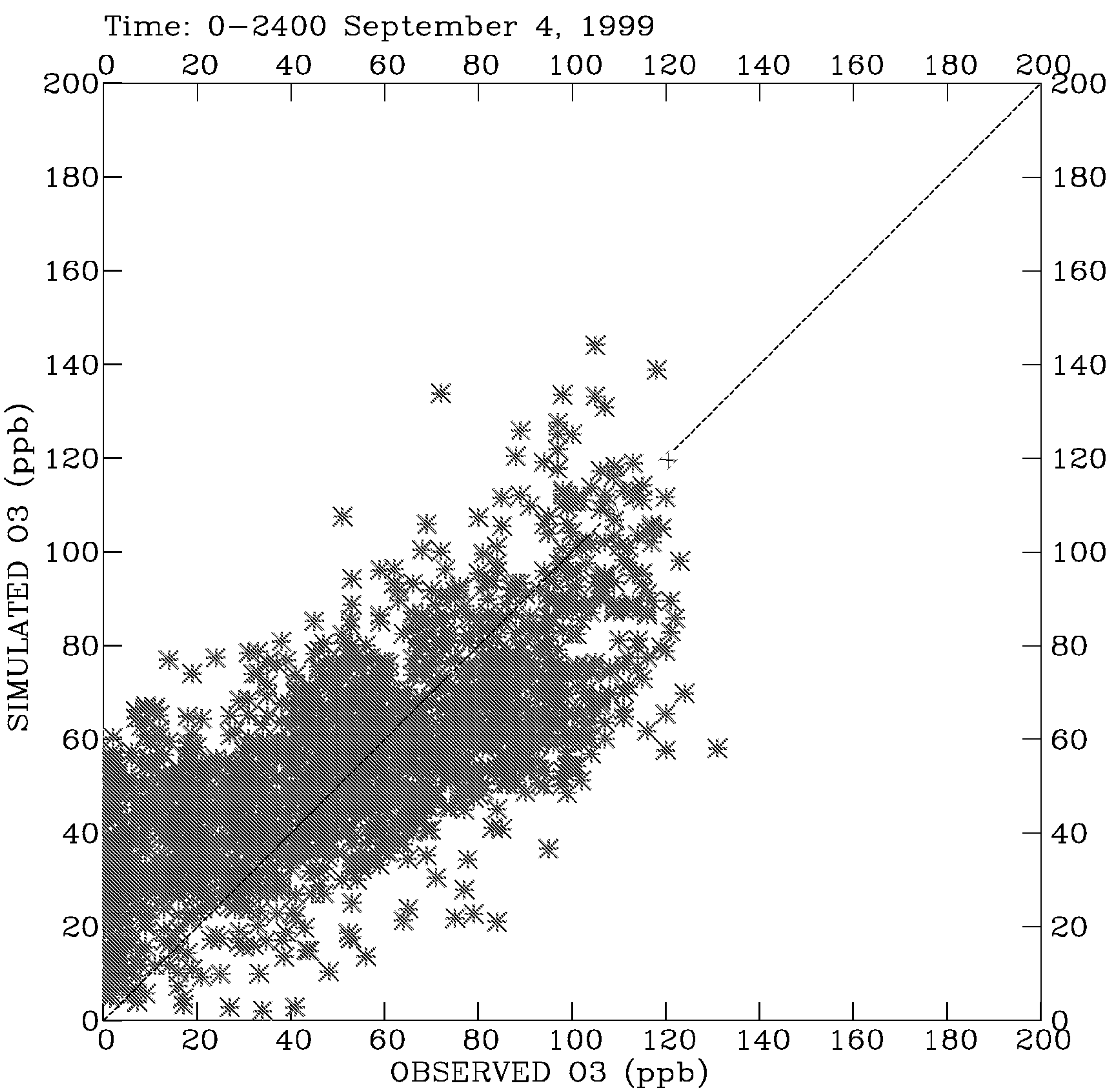
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4f.
Scatter Plot: September 3, 1999



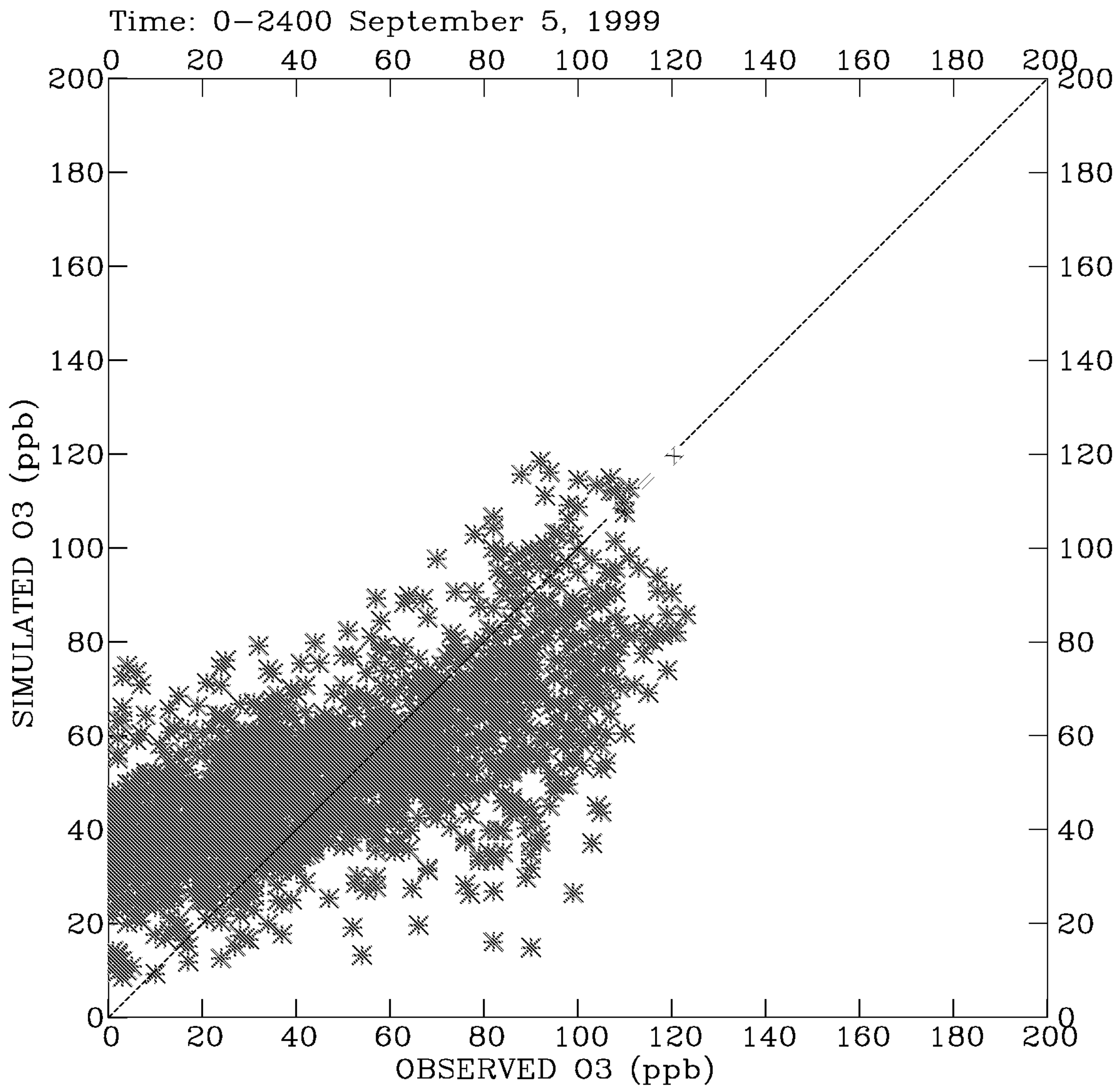
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS−Run08r2
Grid ff3

Figure 6-4g.
Scatter Plot: September 4, 1999



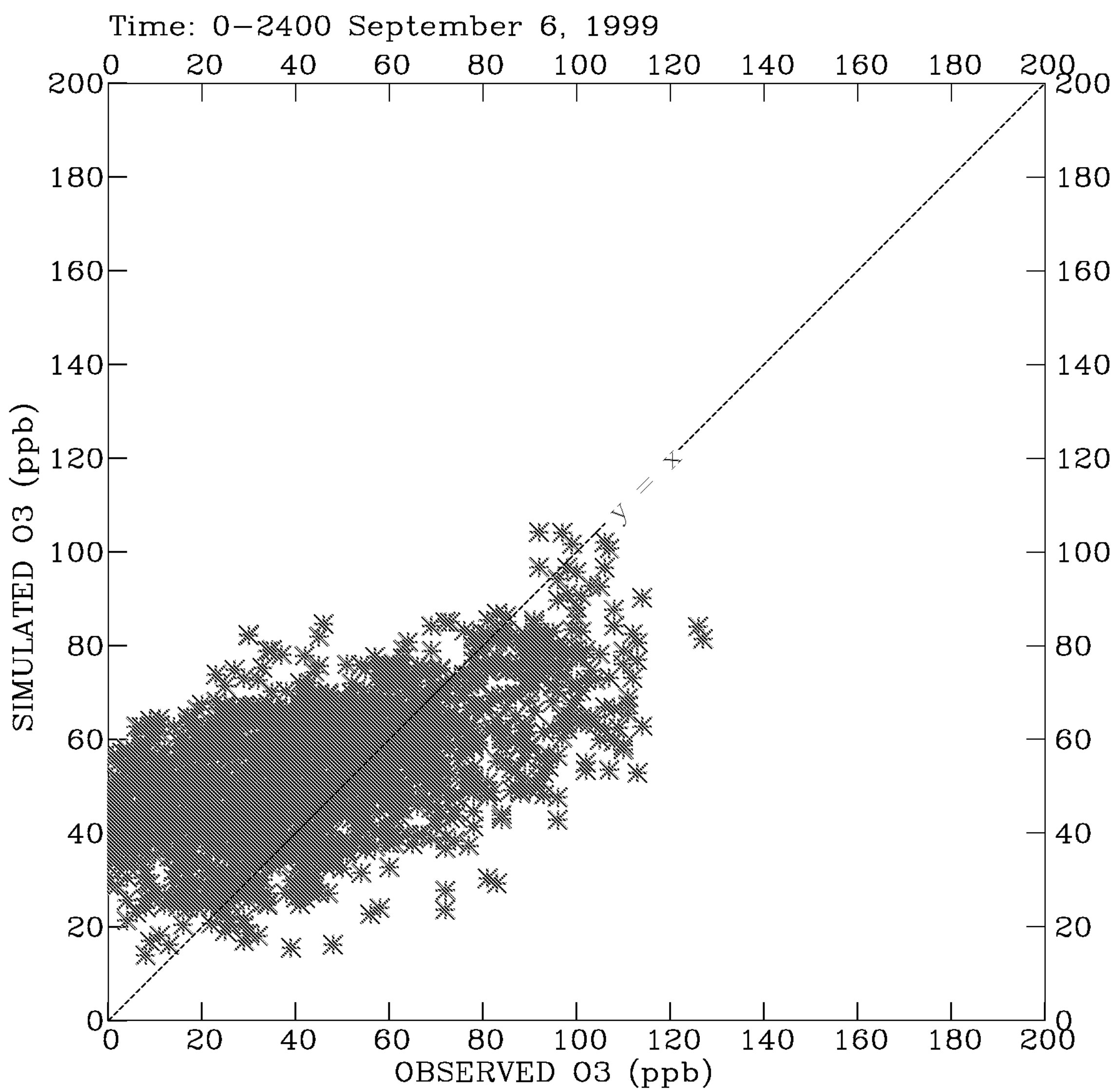
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4h.
Scatter Plot: September 5, 1999



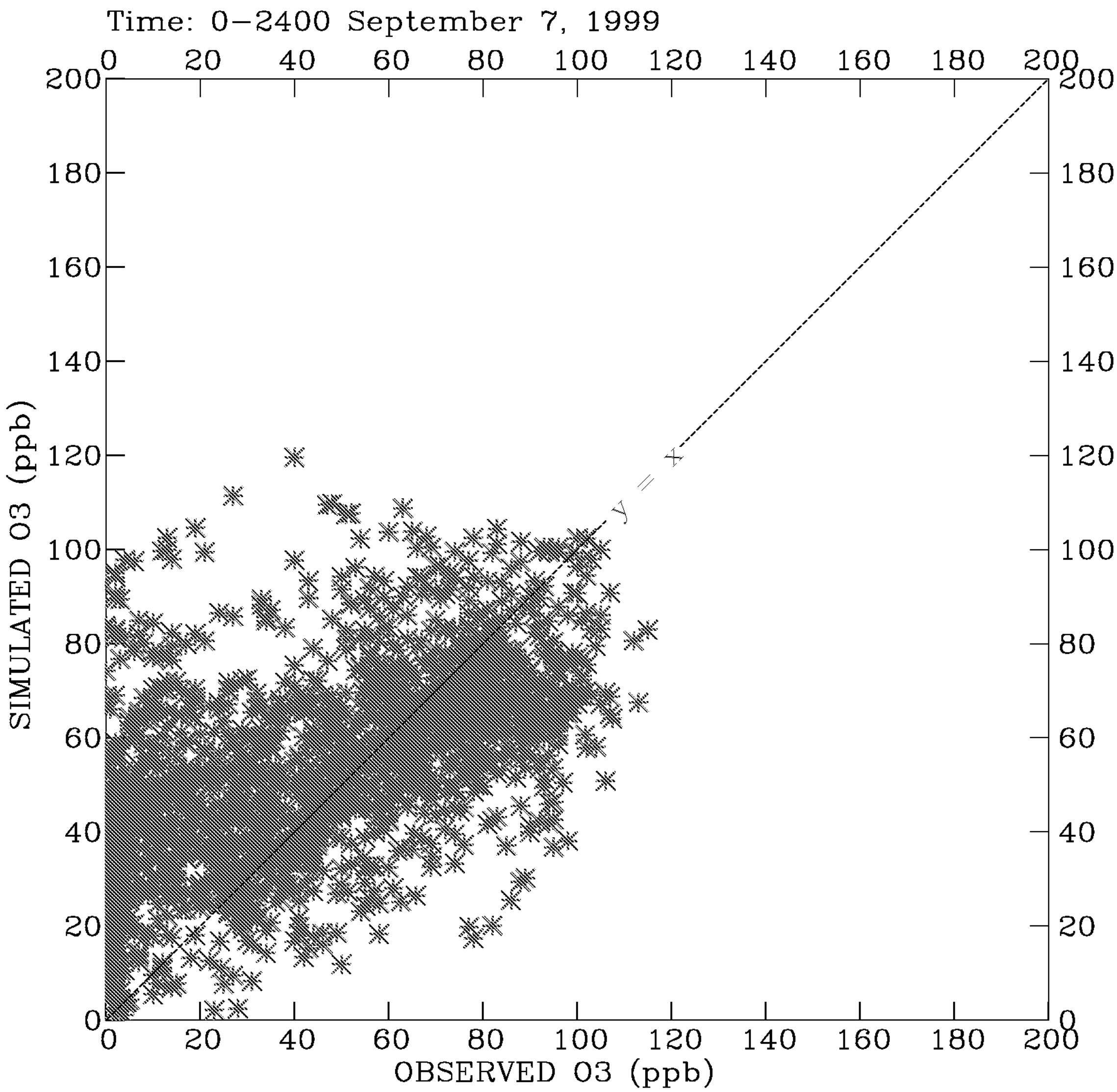
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4i.
Scatter Plot: September 6, 1999



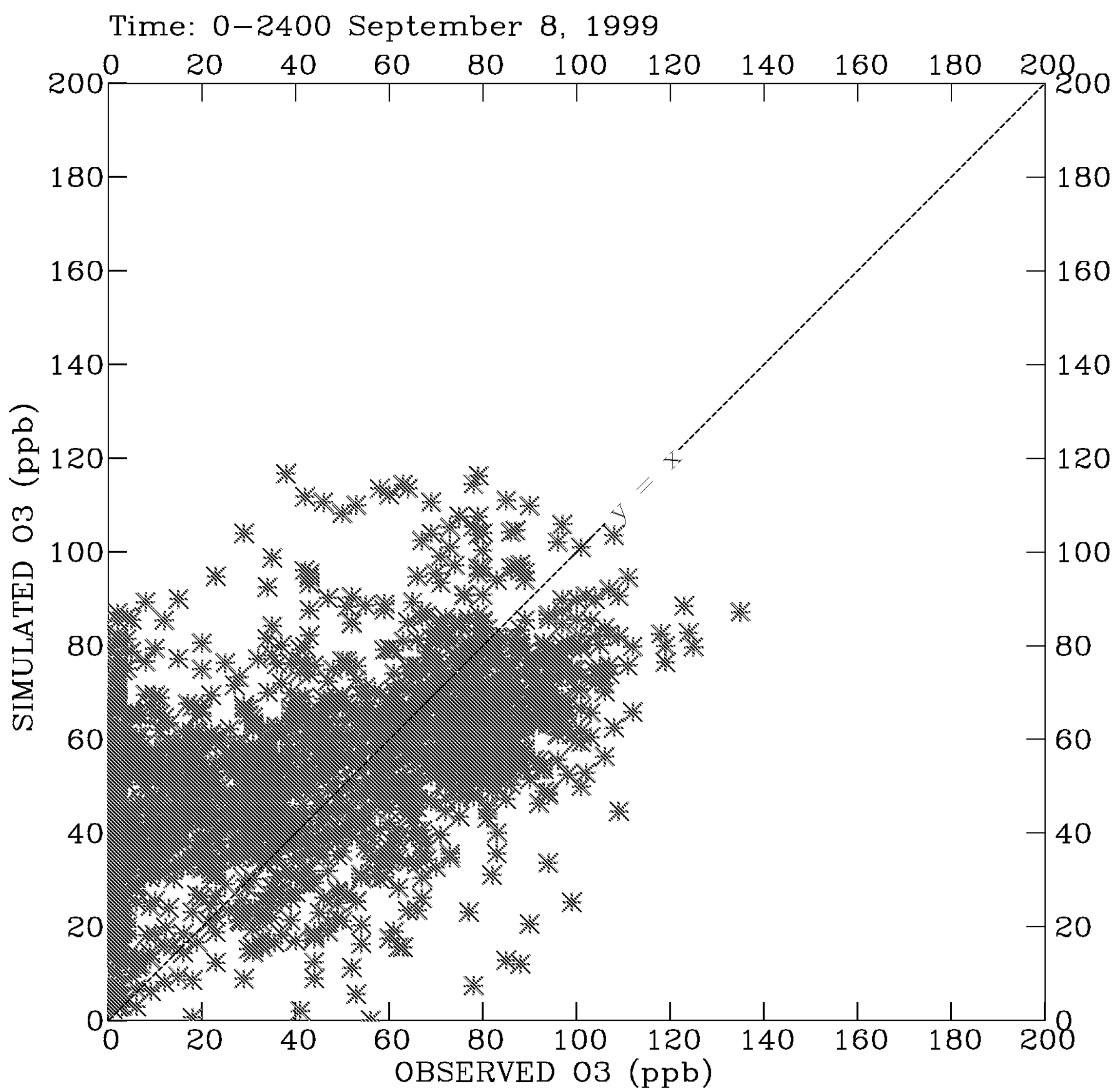
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4j.
Scatter Plot: September 7, 1999



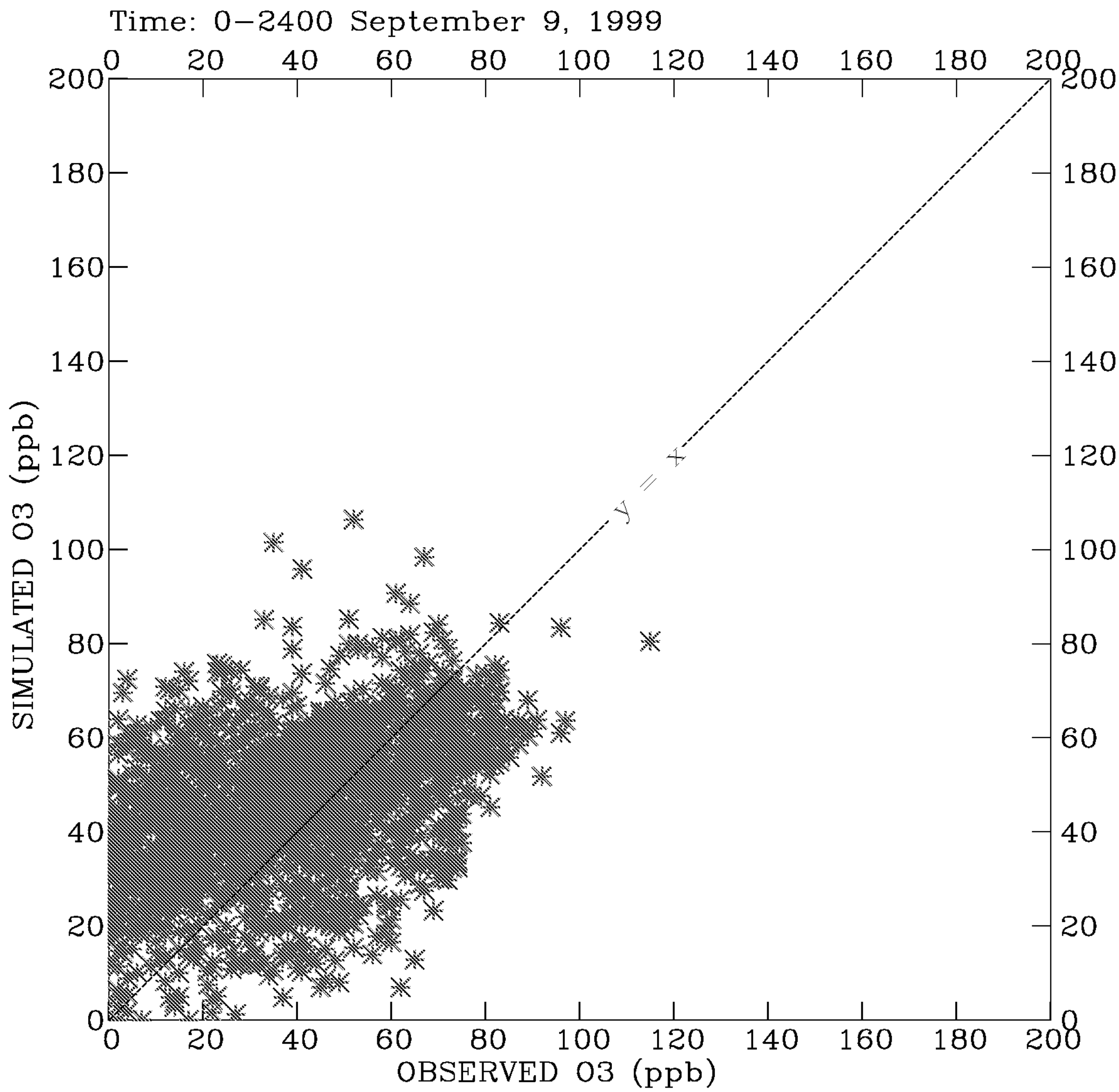
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4k.
Scatter Plot: September 8, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4l.
Scatter Plot: September 9, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-5a.
Daily Maximum 1-Hour Ozone, Grid 1,
June 16, 2001

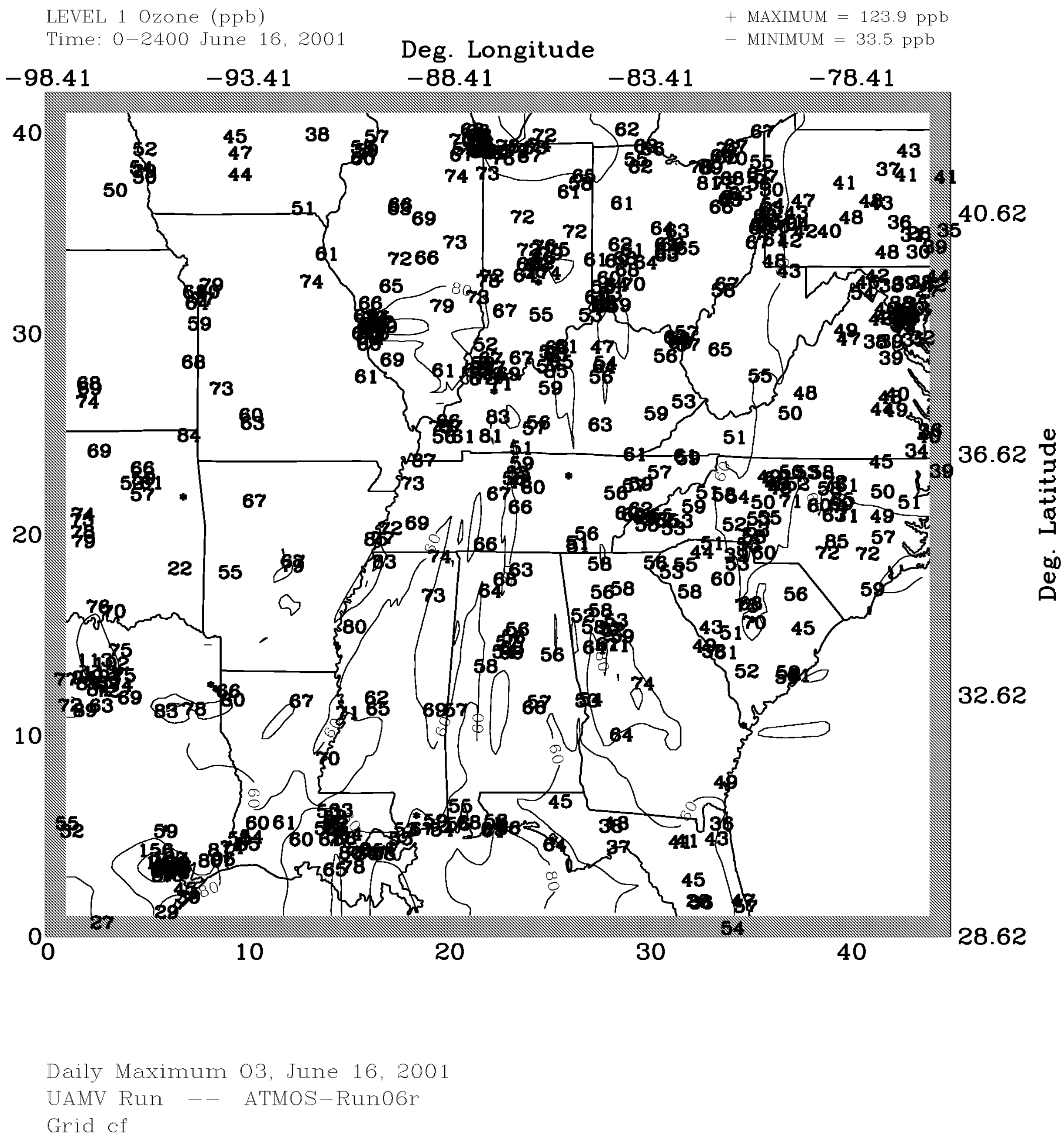


Figure 6-5b.
Daily Maximum 1-Hour Ozone, Grid 1,
June 17, 2001

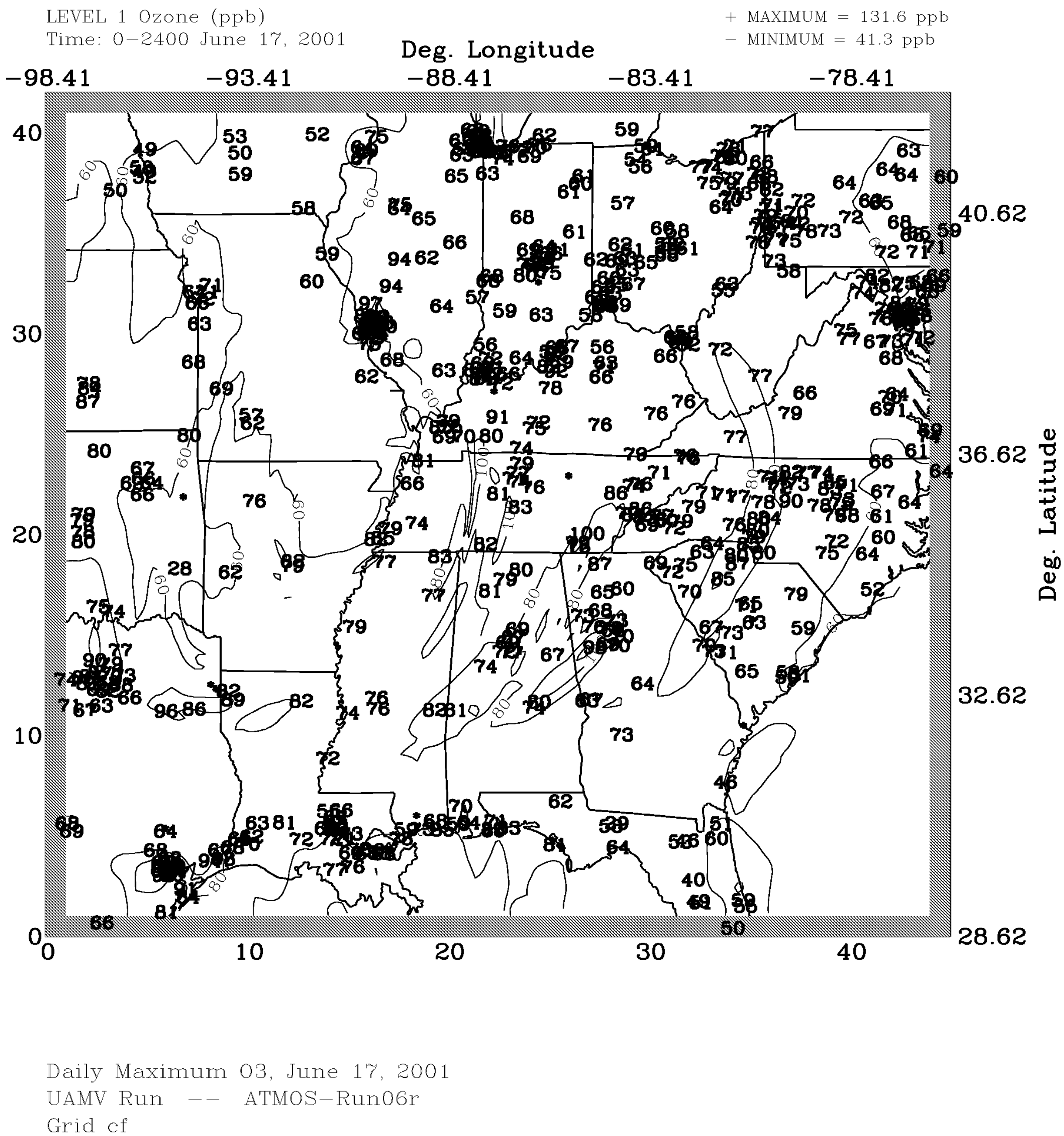


Figure 6-5c.
Daily Maximum 1-Hour Ozone, Grid 1,
June 18, 2001

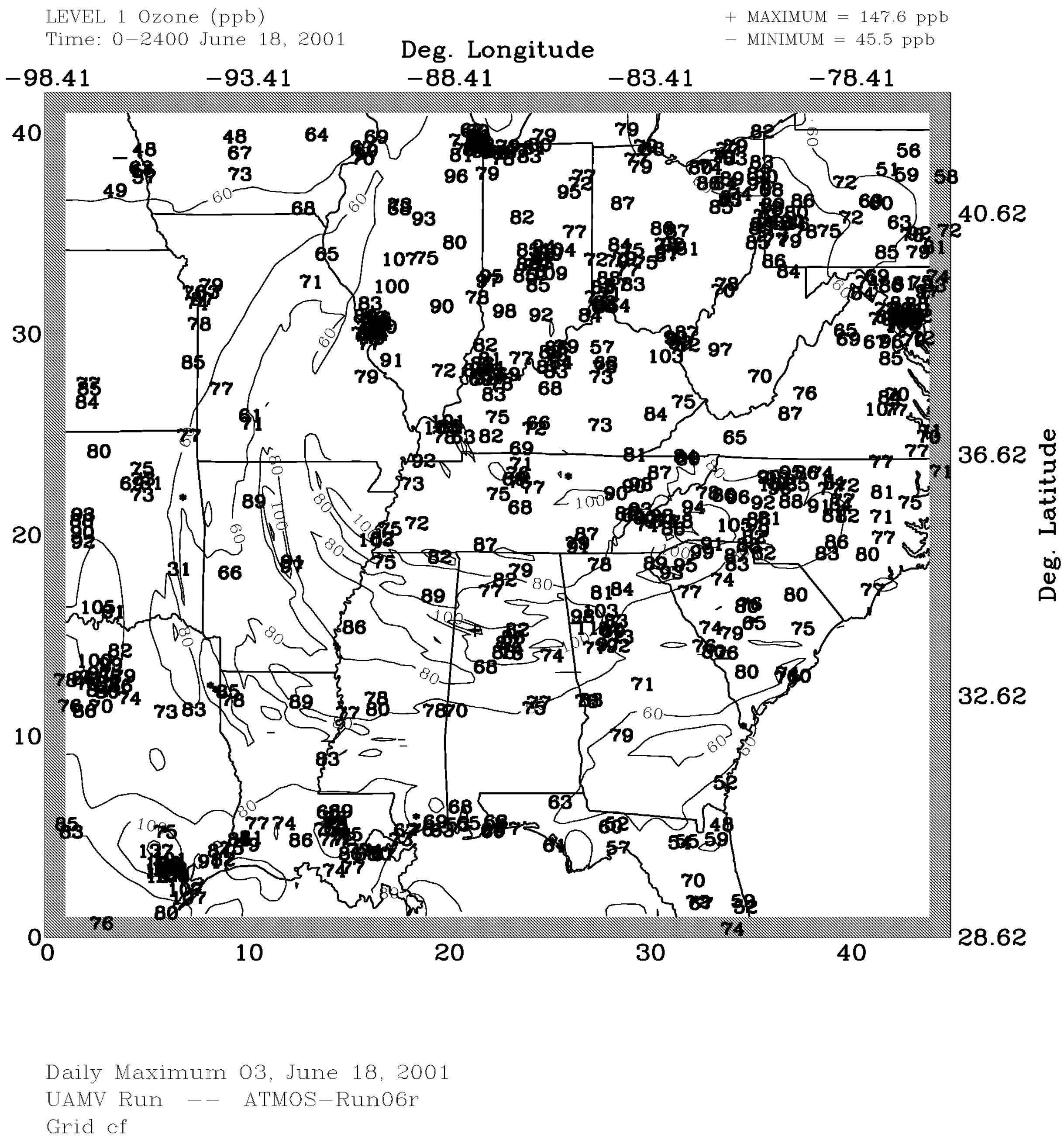


Figure 6-5d.
Daily Maximum 1-Hour Ozone, Grid 1,
June 19, 2001

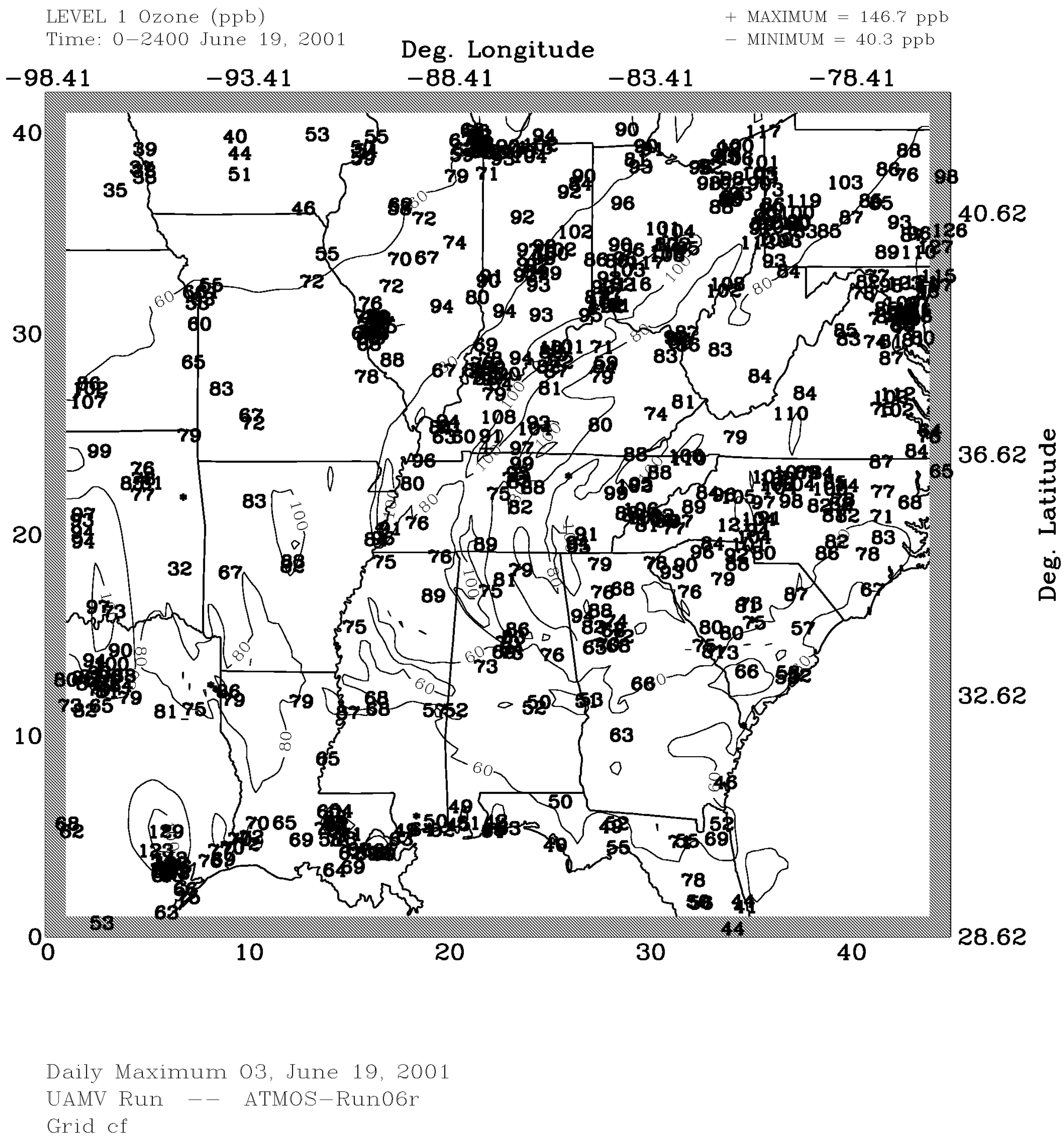


Figure 6-5e.
Daily Maximum 1-Hour Ozone, Grid 1,
June 20, 2001

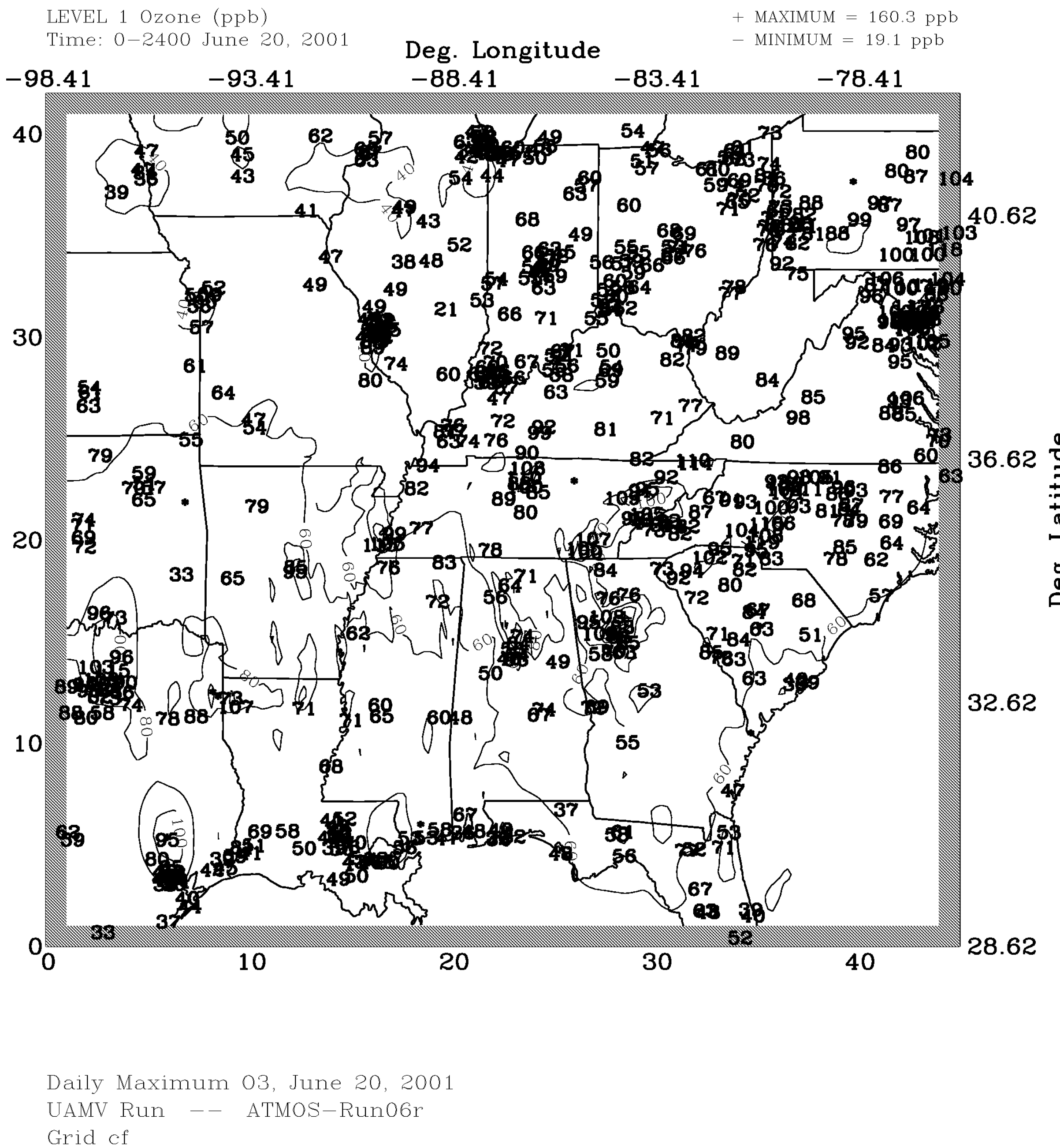
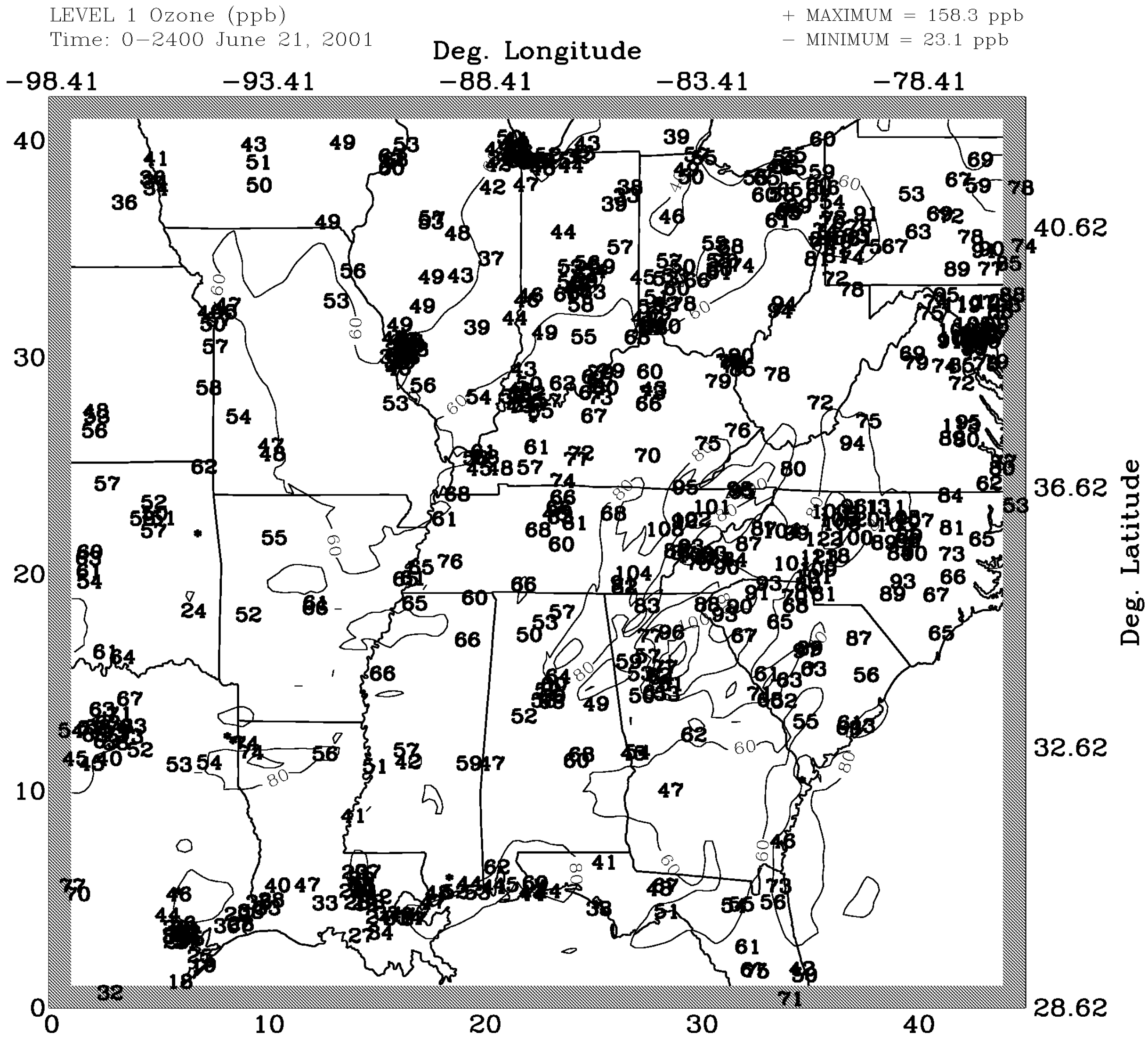


Figure 6-5f.
Daily Maximum 1-Hour Ozone, Grid 1,
June 21, 2001



Daily Maximum 03, June 21, 2001
UAMV Run −− ATMOS−Run06r
Grid cf

Figure 6-5g.
Daily Maximum 1-Hour Ozone, Grid 1,
June 22, 2001

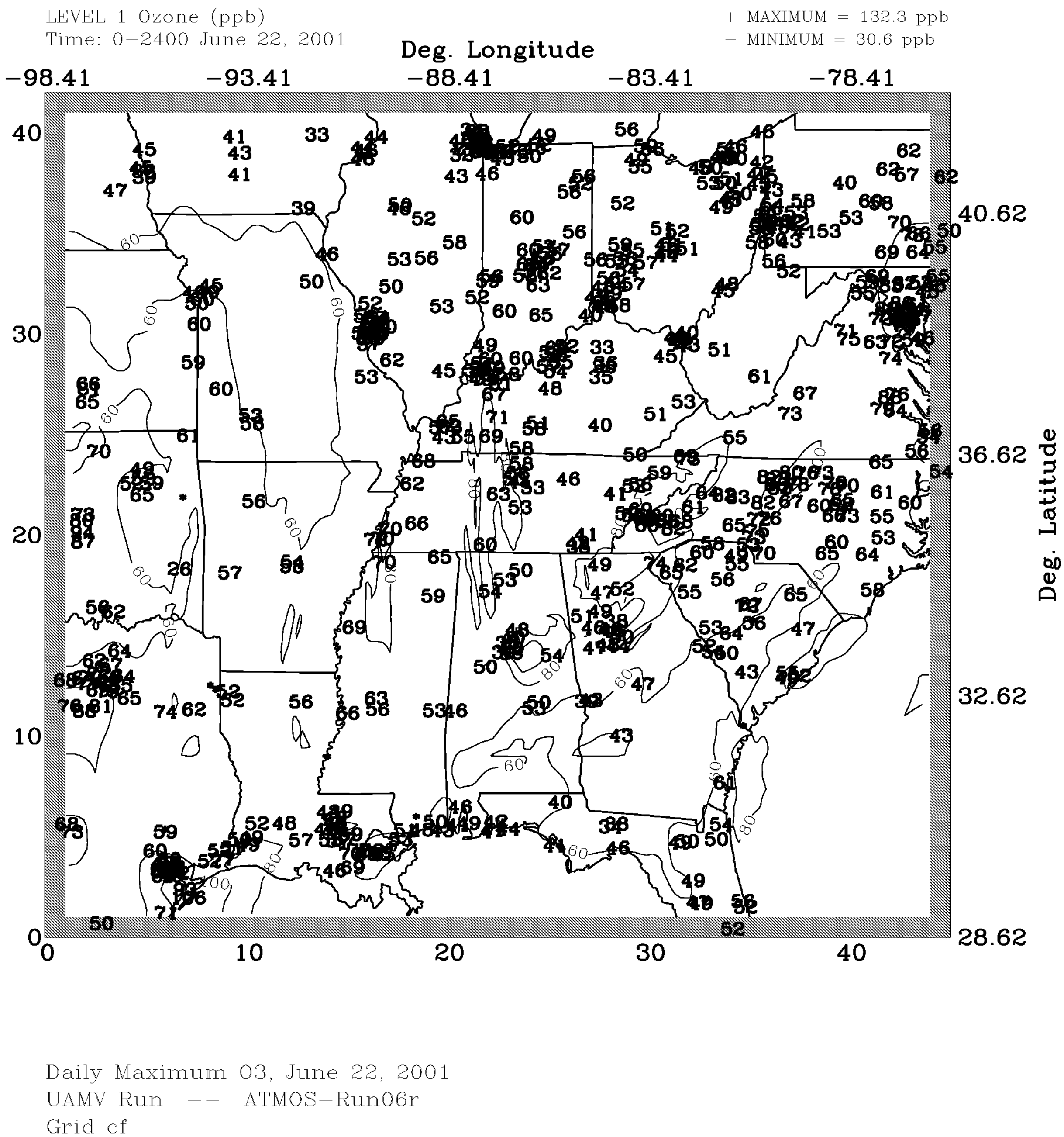


Figure 6-6a.
Daily Maximum 1-Hour Ozone, Grid 3,
June 16, 2001

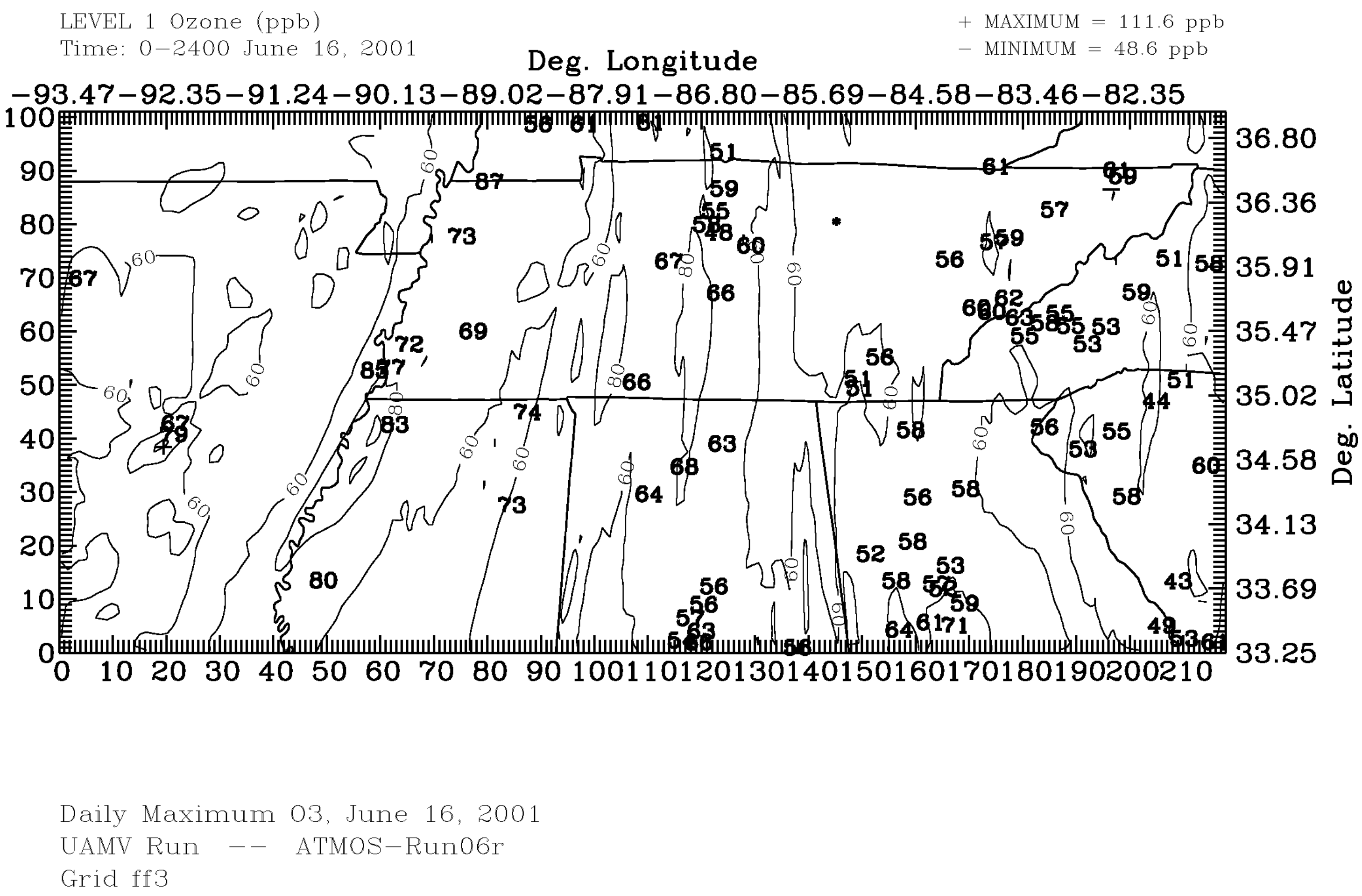


Figure 6-6b.
Daily Maximum 1-Hour Ozone, Grid 3,
June 17, 2001

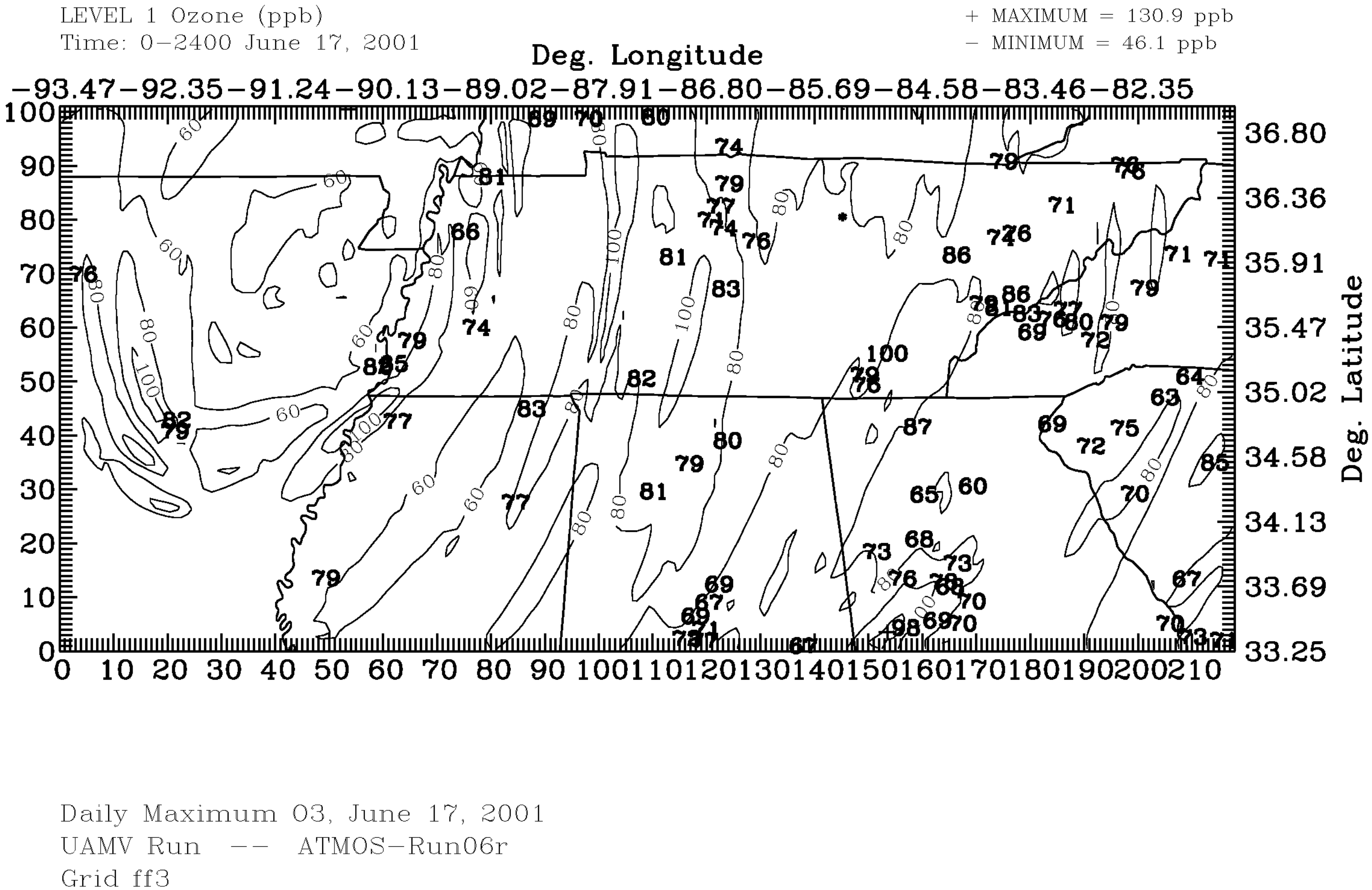


Figure 6-6c.
Daily Maximum 1-Hour Ozone, Grid 3
June 18, 2001

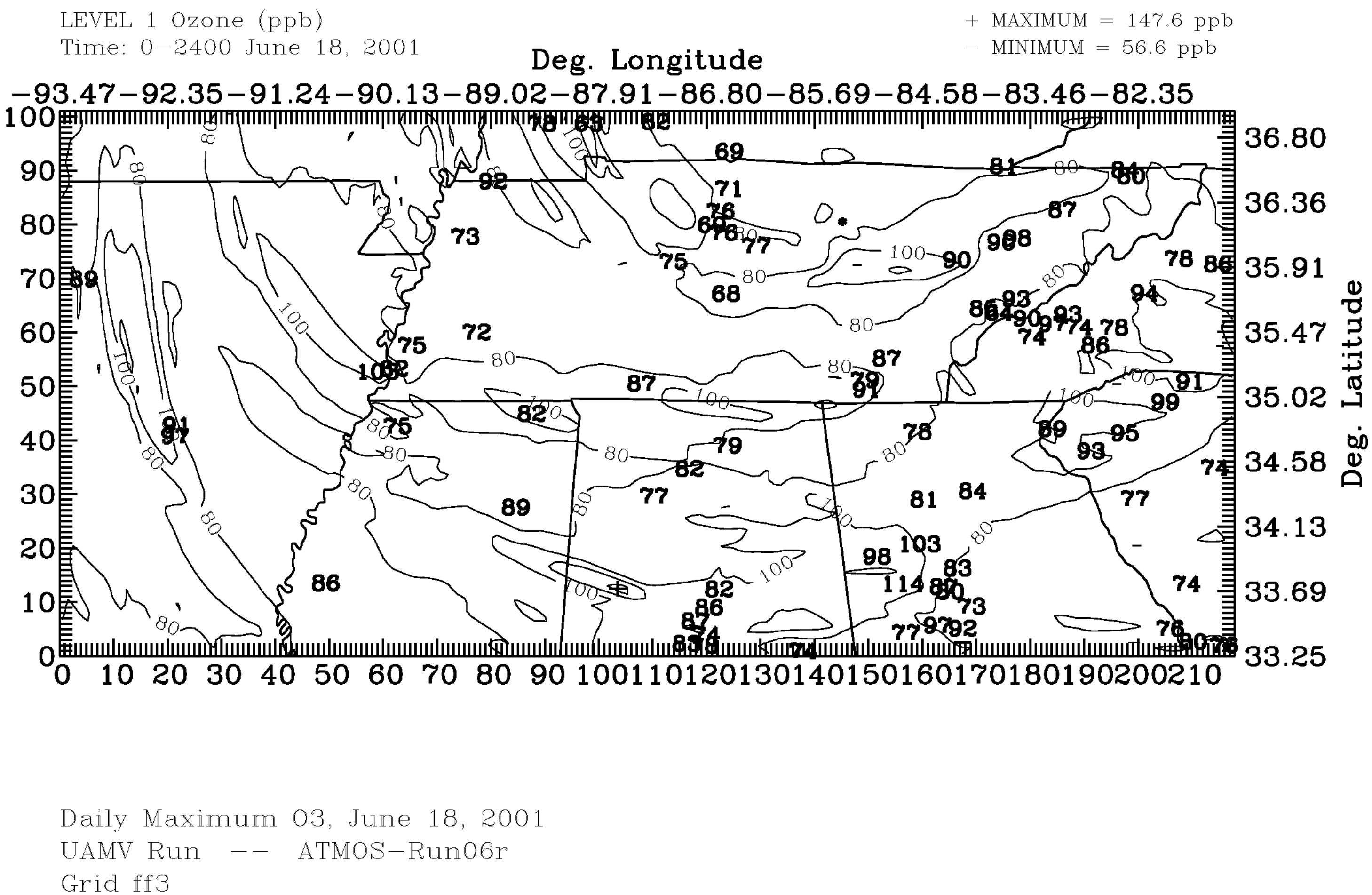


Figure 6-6d.
Daily Maximum 1-Hour Ozone, Grid 3
June 19, 2001

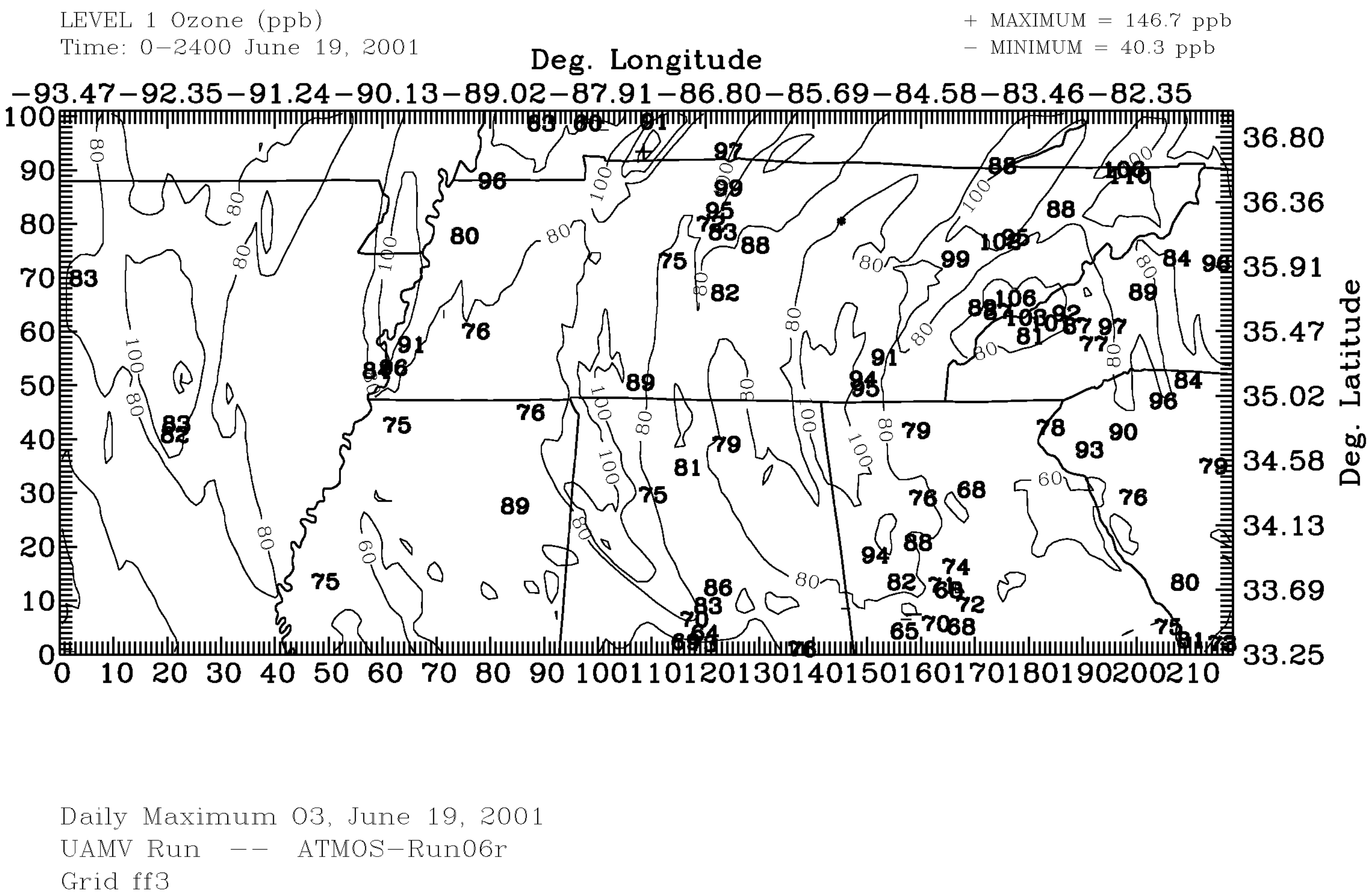
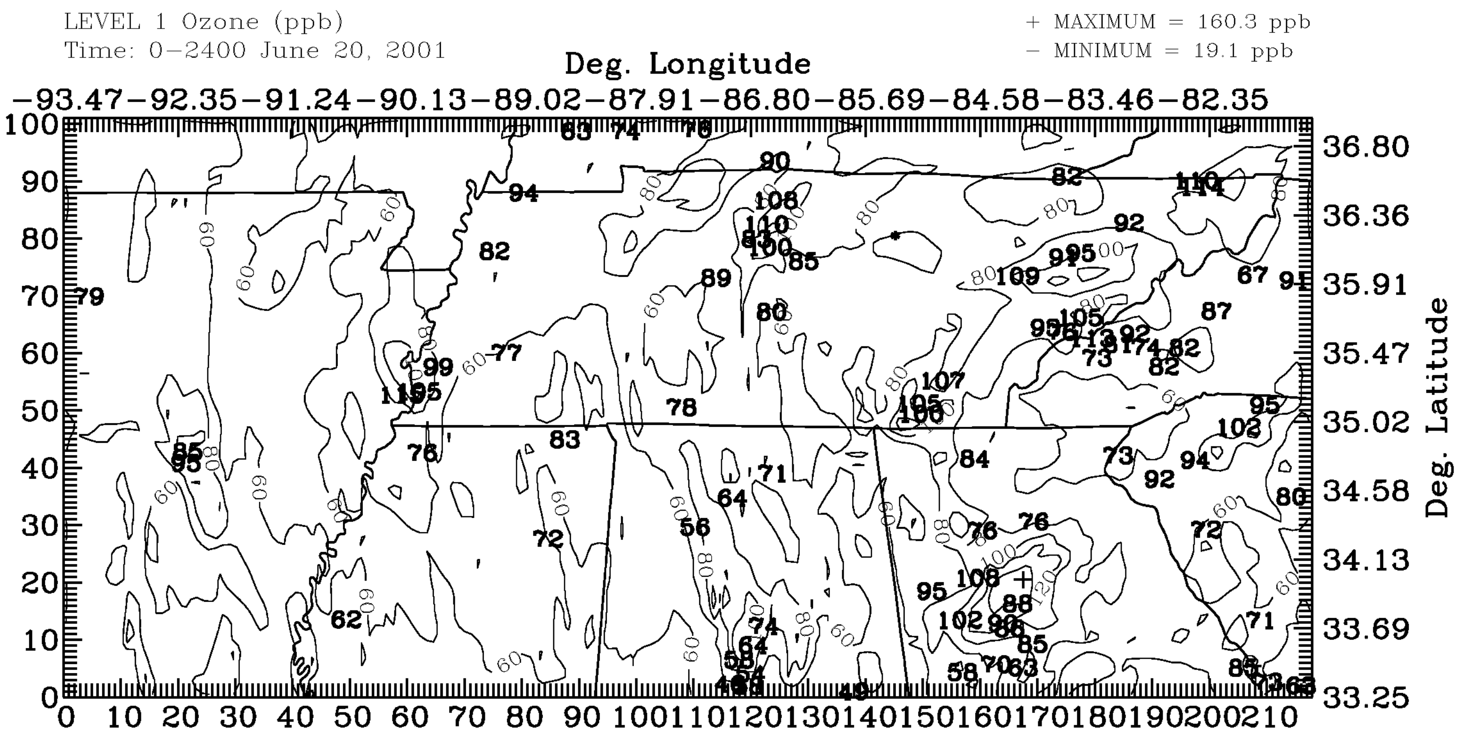


Figure 6-6e.
Daily Maximum 1-Hour Ozone, Grid 3
June 20, 2001



Daily Maximum O3, June 20, 2001
UAMV Run -- ATMOS–Run06r
Grid ff3

Figure 6-6f.
Daily Maximum 1-Hour Ozone, Grid 3
June 21, 2001

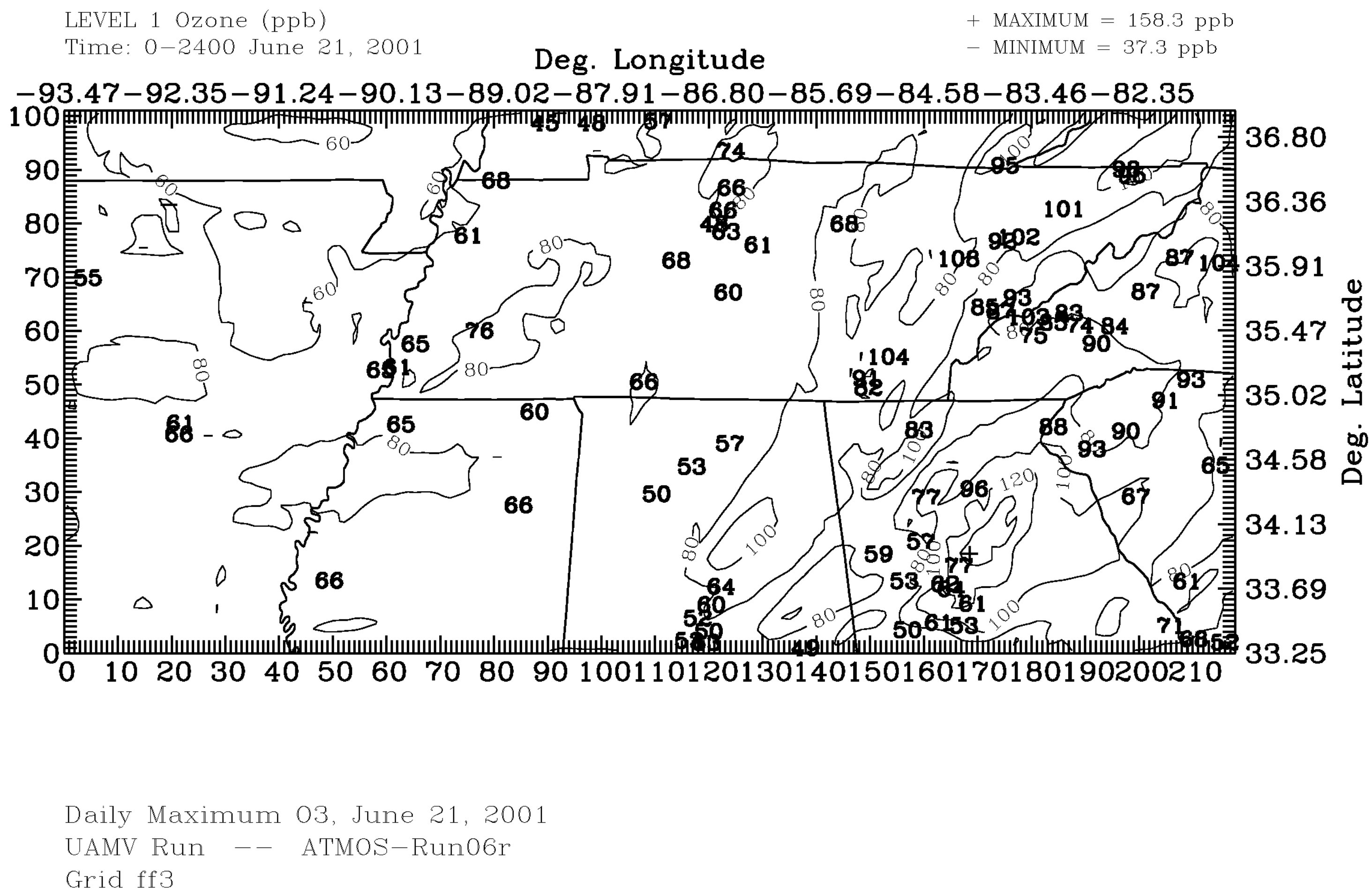


Figure 6-6g.
Daily Maximum 1-Hour Ozone, Grid 3
June 22, 2001

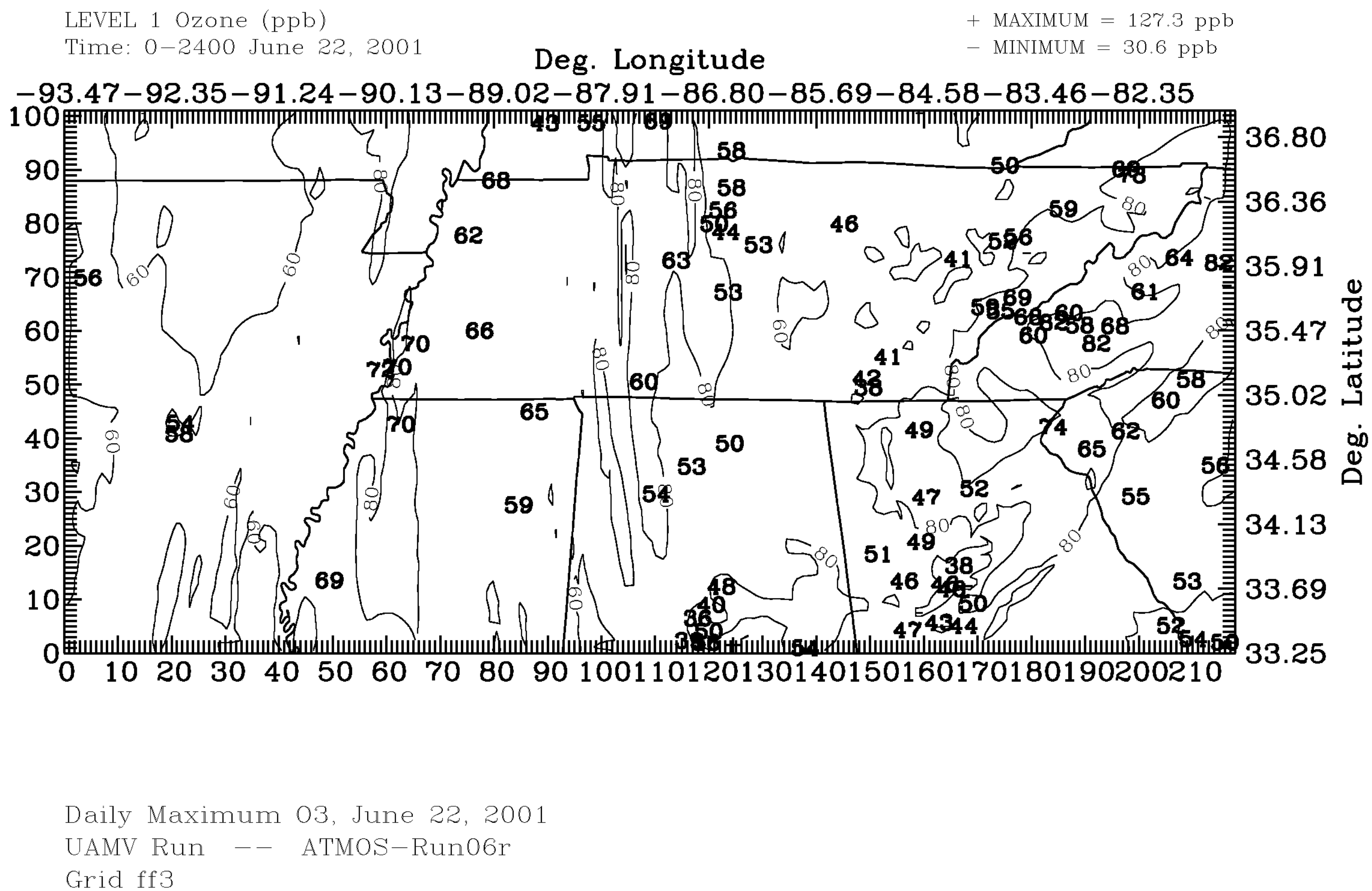


Figure 6-7a.
2001 Episode Time Series: Memphis EAC area
June 16-19, 2001

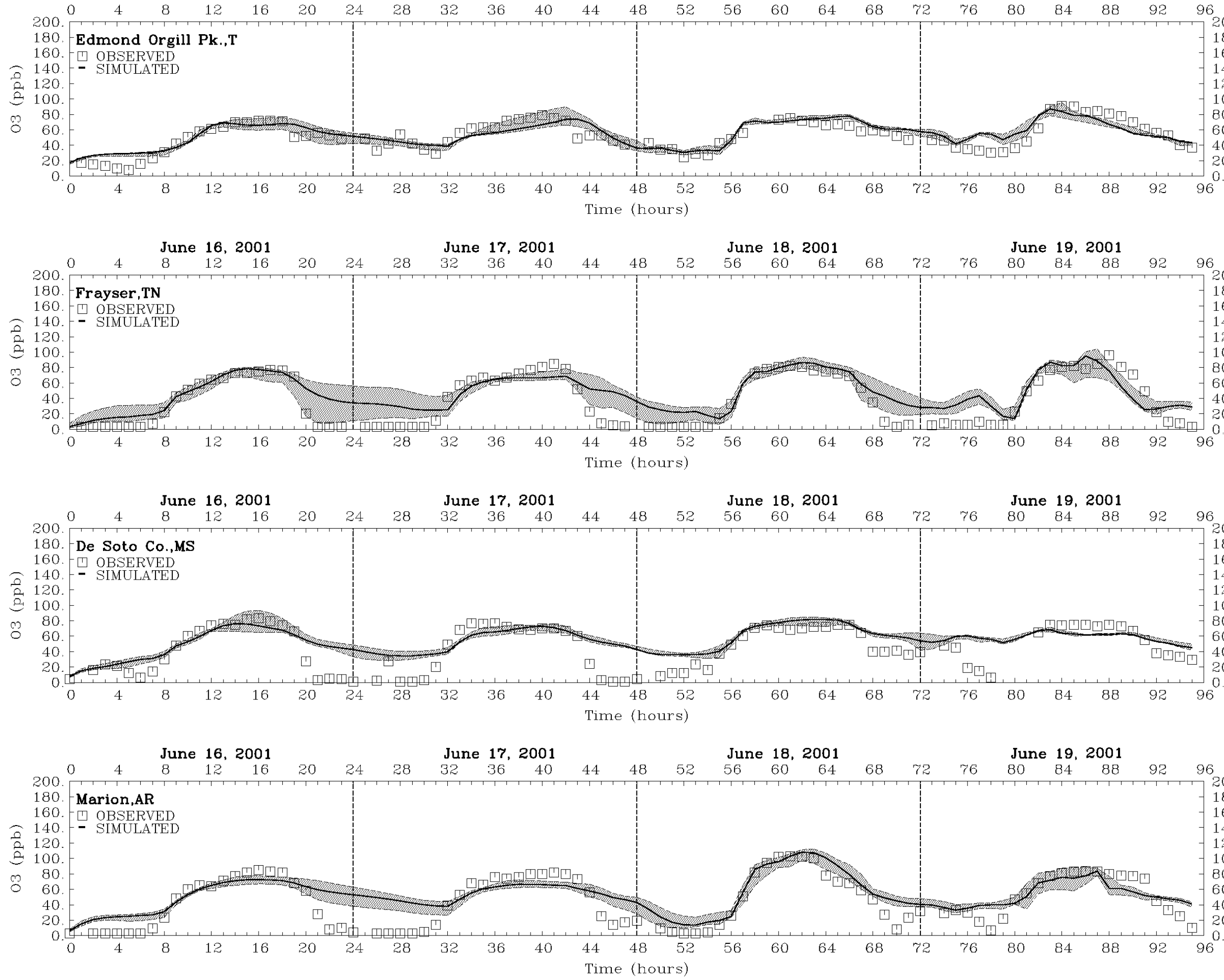


Figure 6-7b.
2001 Episode Time Series: Memphis EAC Area,
June 19-22, 2001

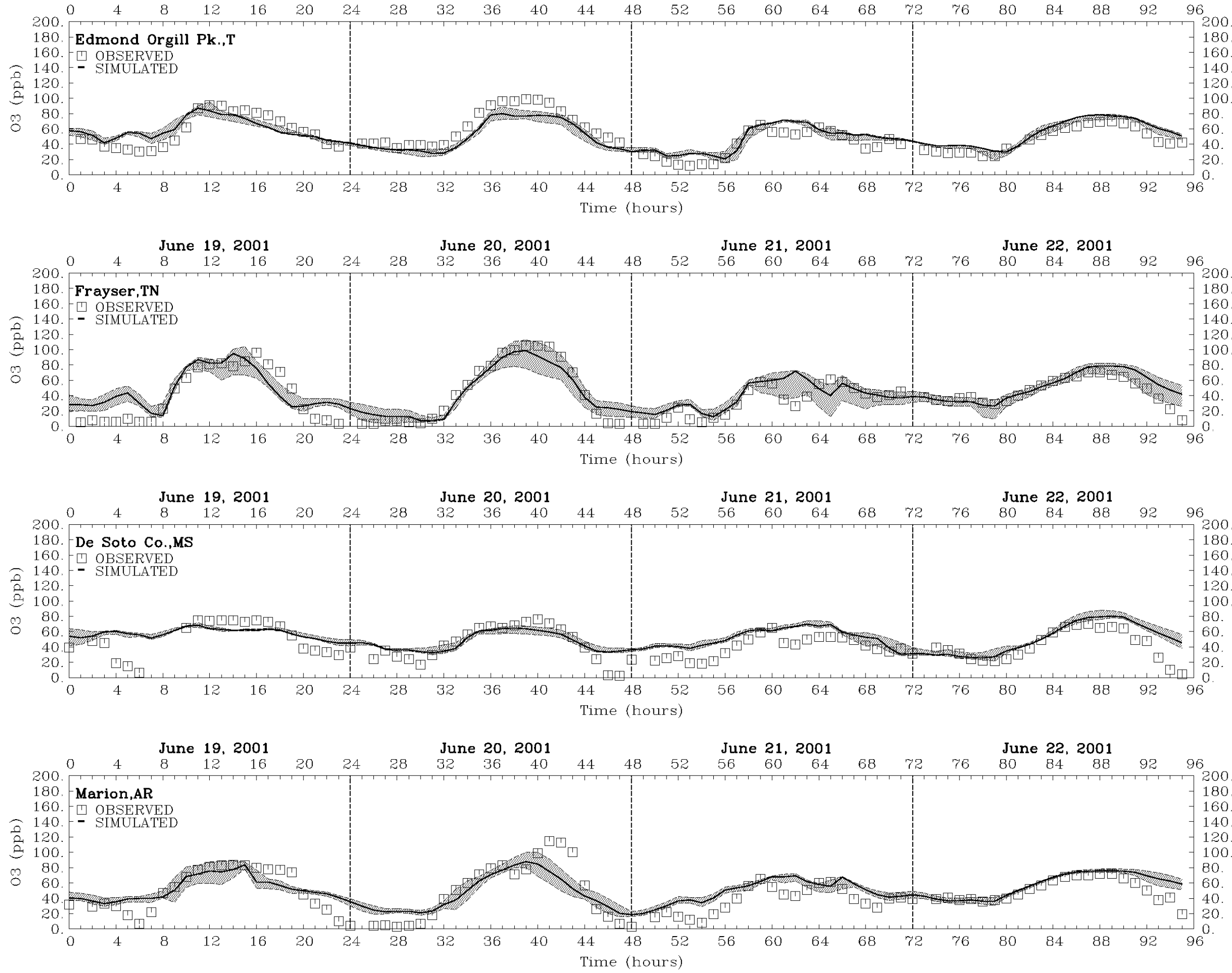


Figure 6-7c.
2001 Episode Time Series: Nashville EAC Area,
June 16-19, 2001

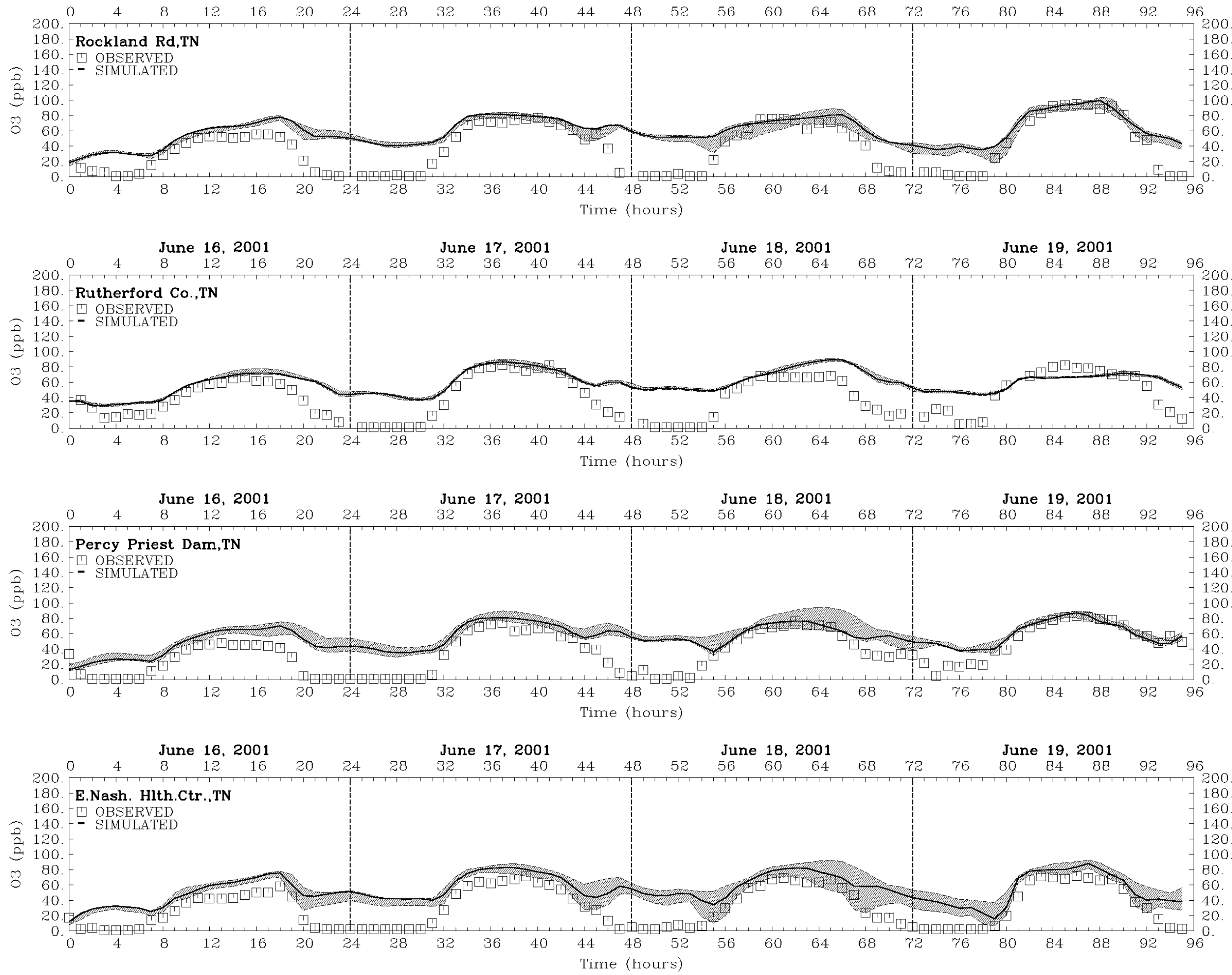


Figure 6-7d.
2001 Episode Time Series: Nashville EAC Area ***(continued)*****,**
June 16-19, 2001

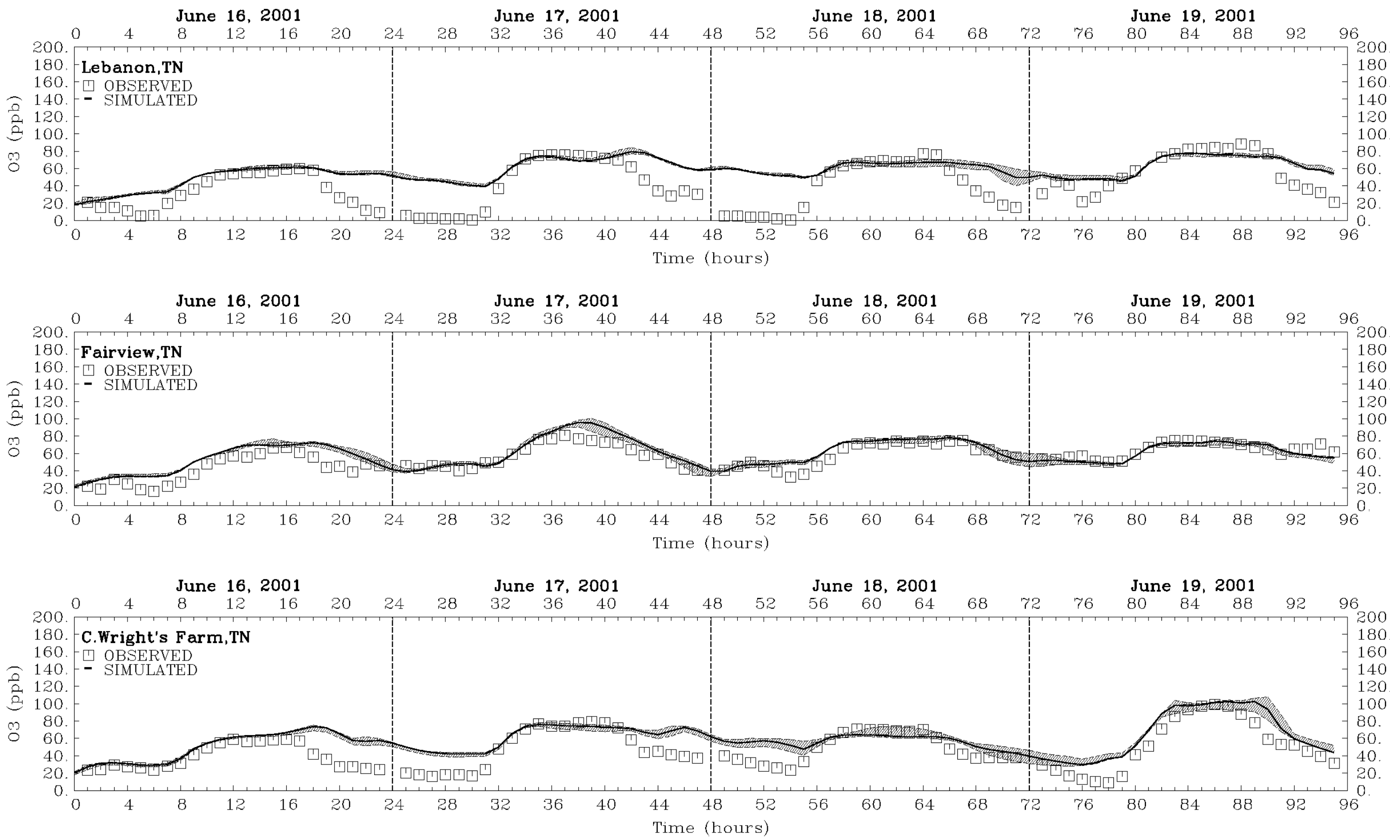


Figure 6-7e.
2001 Episode Time Series: Nashville EAC Area,
June 19-22, 2001

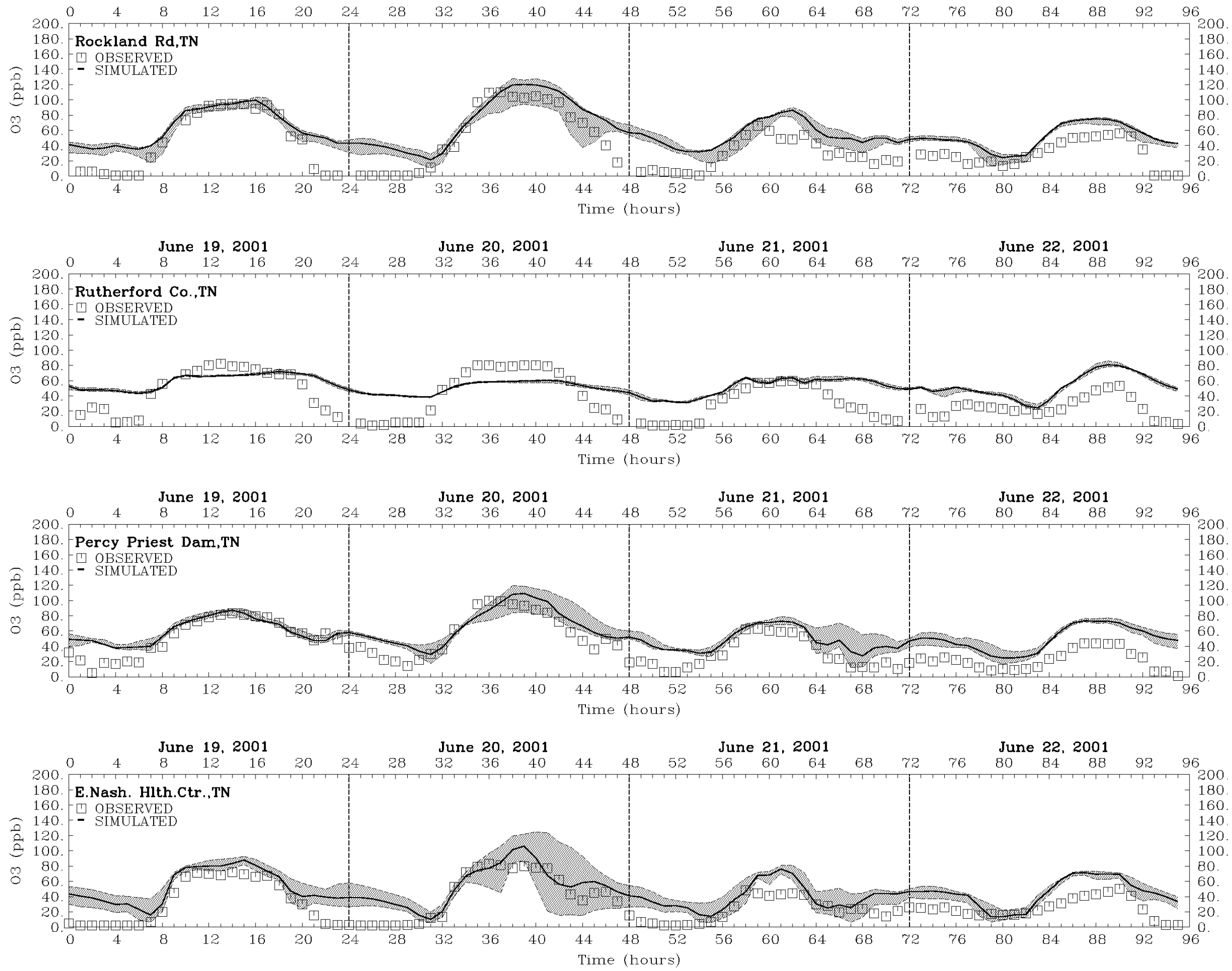


Figure 6-7f.
2001 Episode Time Series: Nashville EAC Area *(continued)*,
June 19-22, 2001

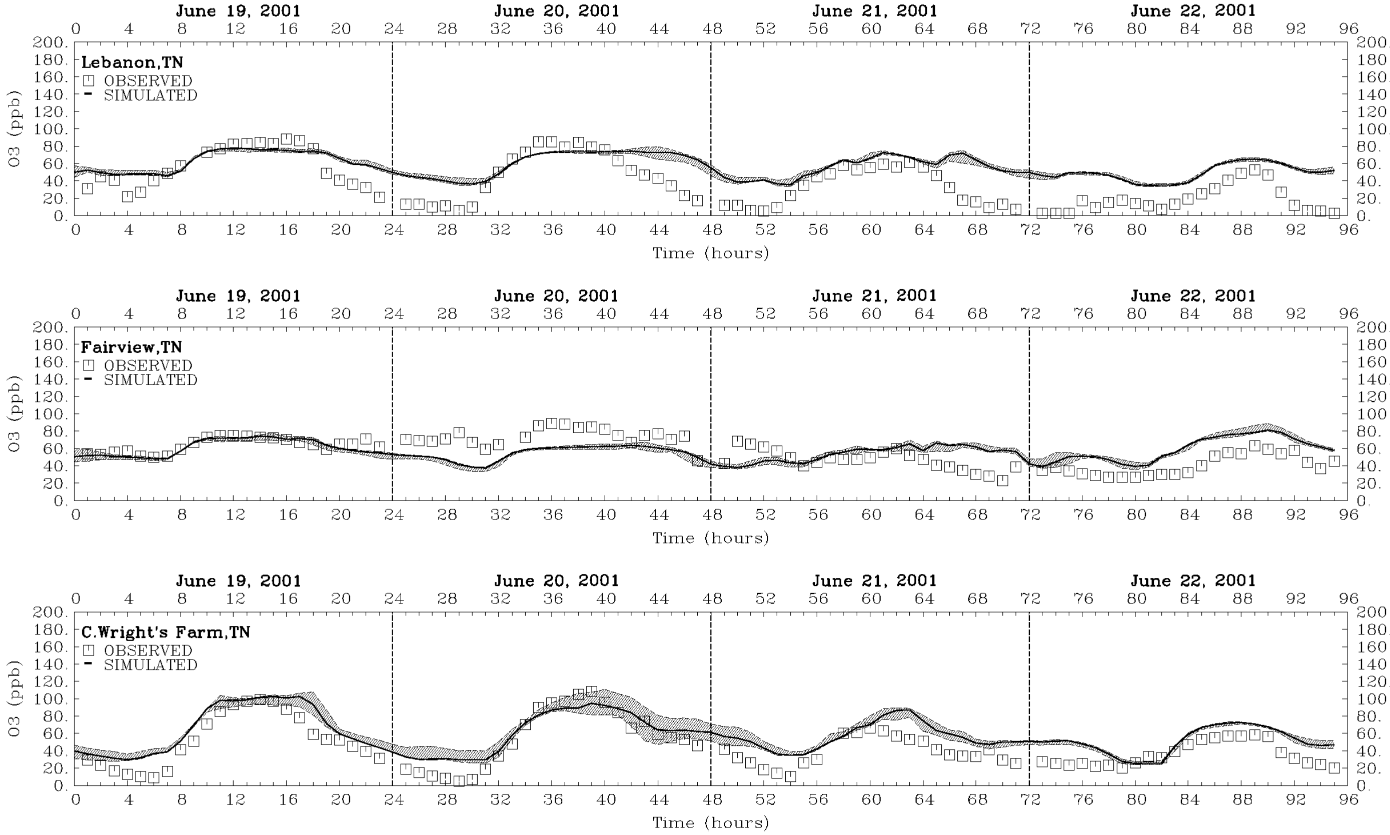


Figure 6-7g.
2001 Episode Time Series: Knoxville EAC Area,
June 16-19, 2001

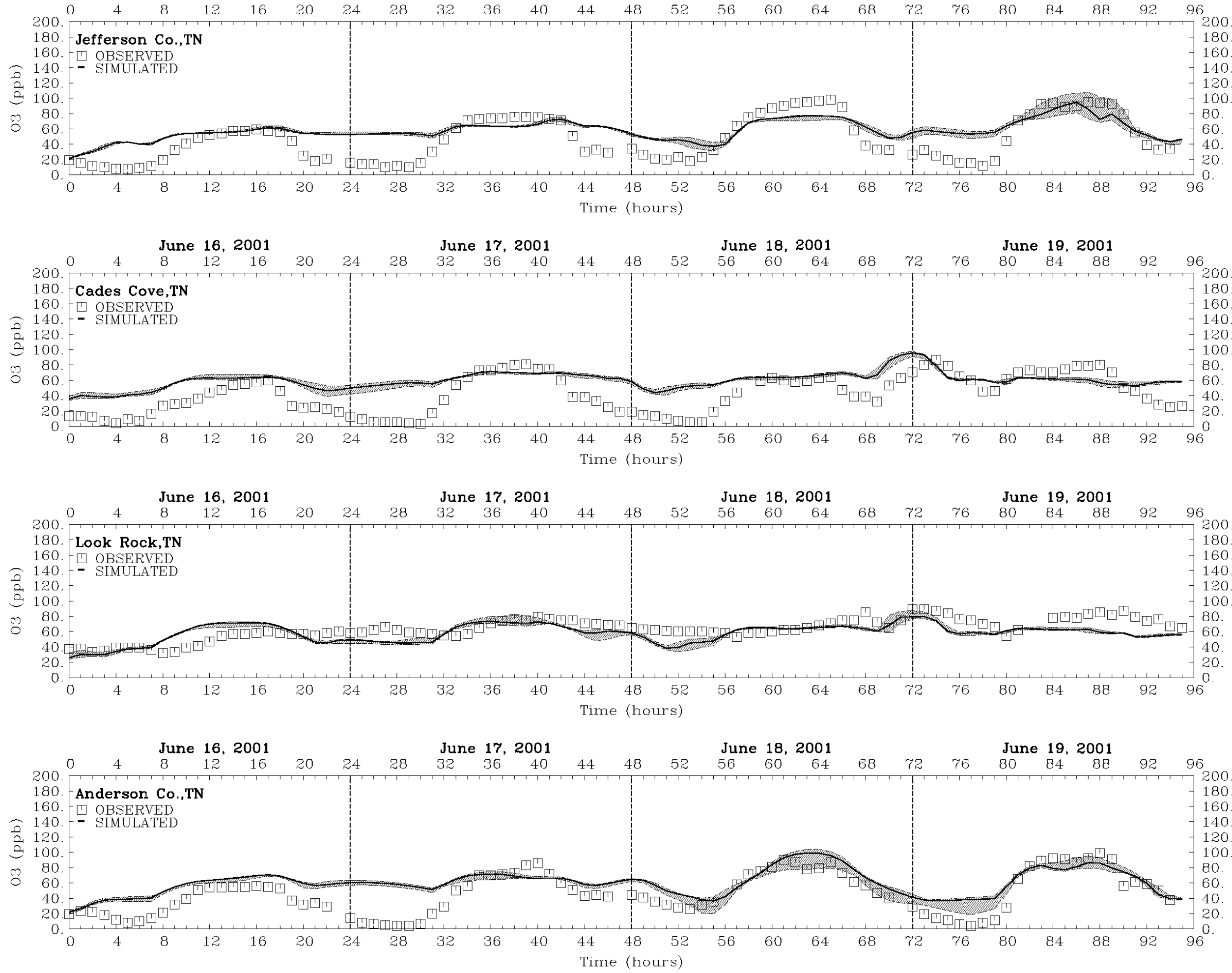


Figure 6-7h.
2001 Episode Time Series: Knoxville EAC Area ***(continued)*****,)**
June 16-19, 2001

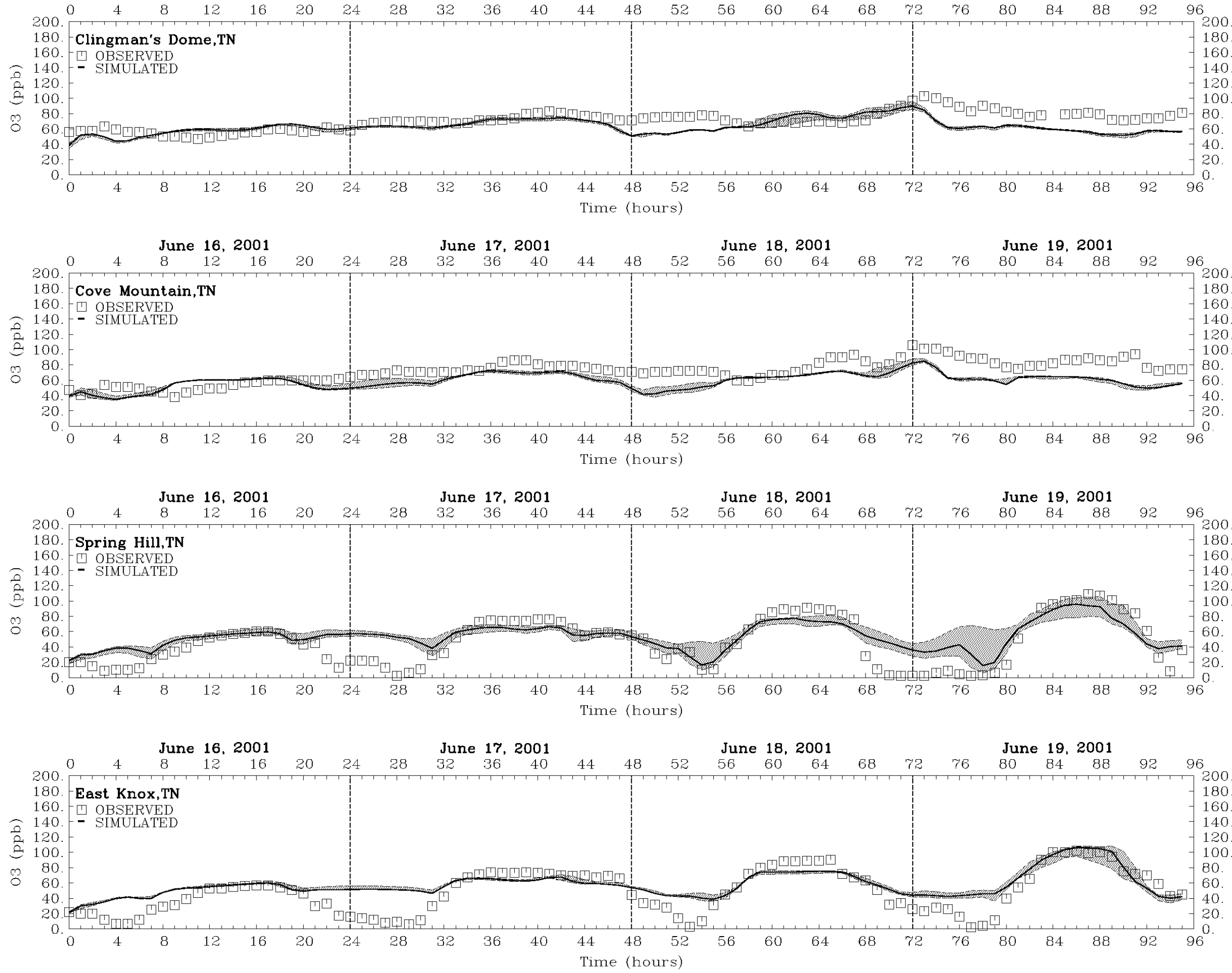


Figure 6-7i.
2001 Episode Time Series: Knoxville EAC Area,
June 19-22, 2001

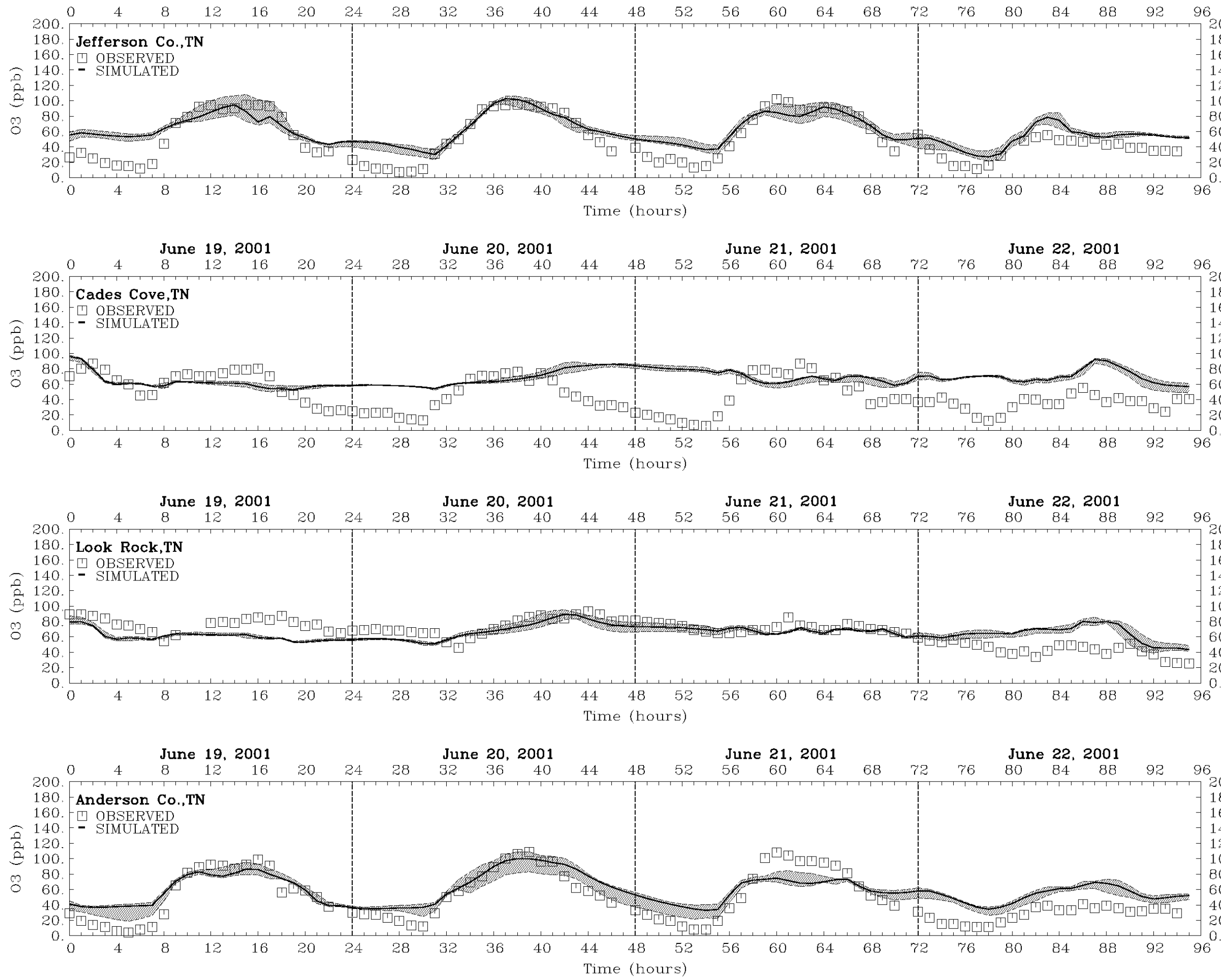


Figure 6-7j.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,
June 19-22, 2001

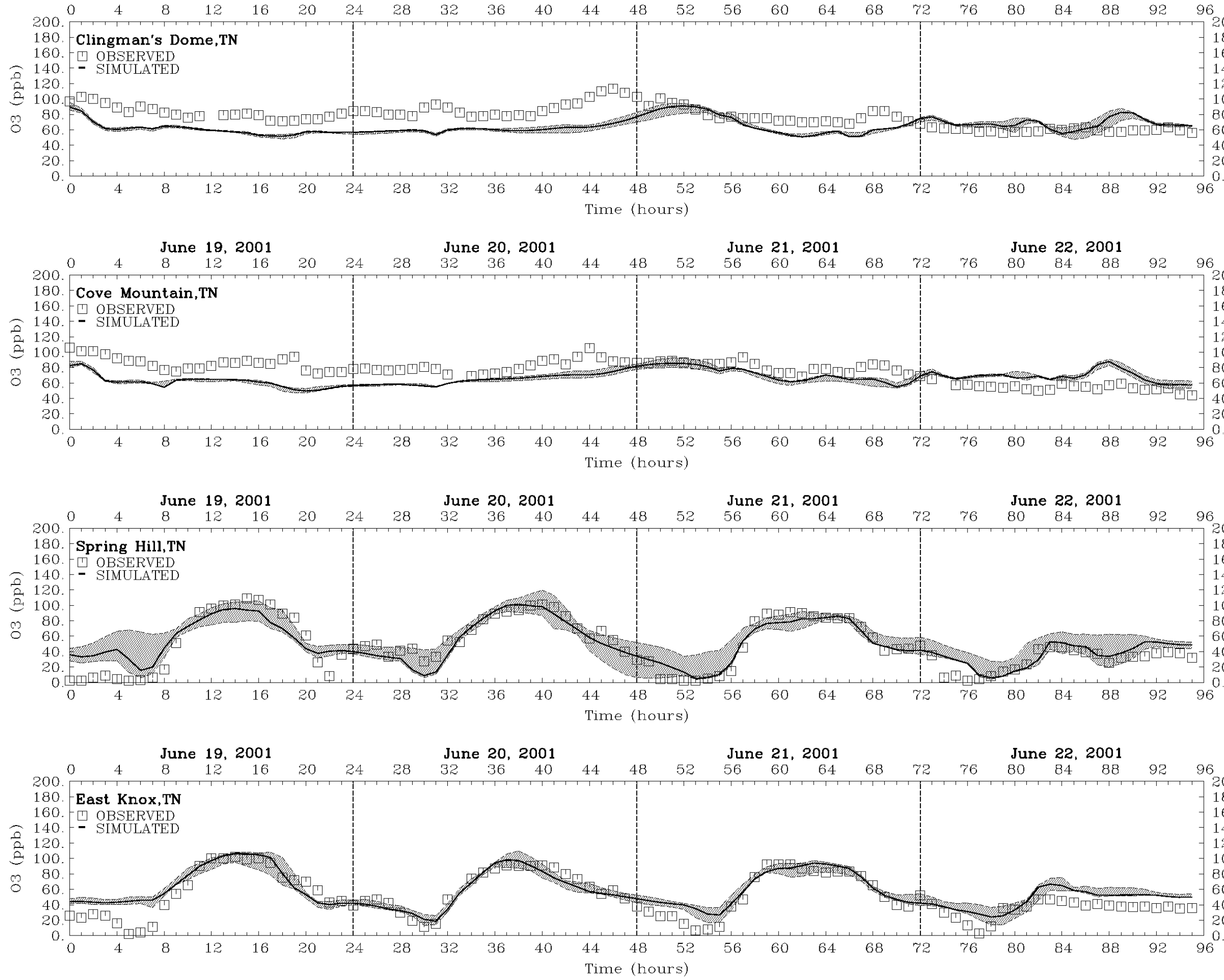


Figure 6-7k.
2001 Episode Time Series: Chattanooga EAC Area,
June 16-19, 2001

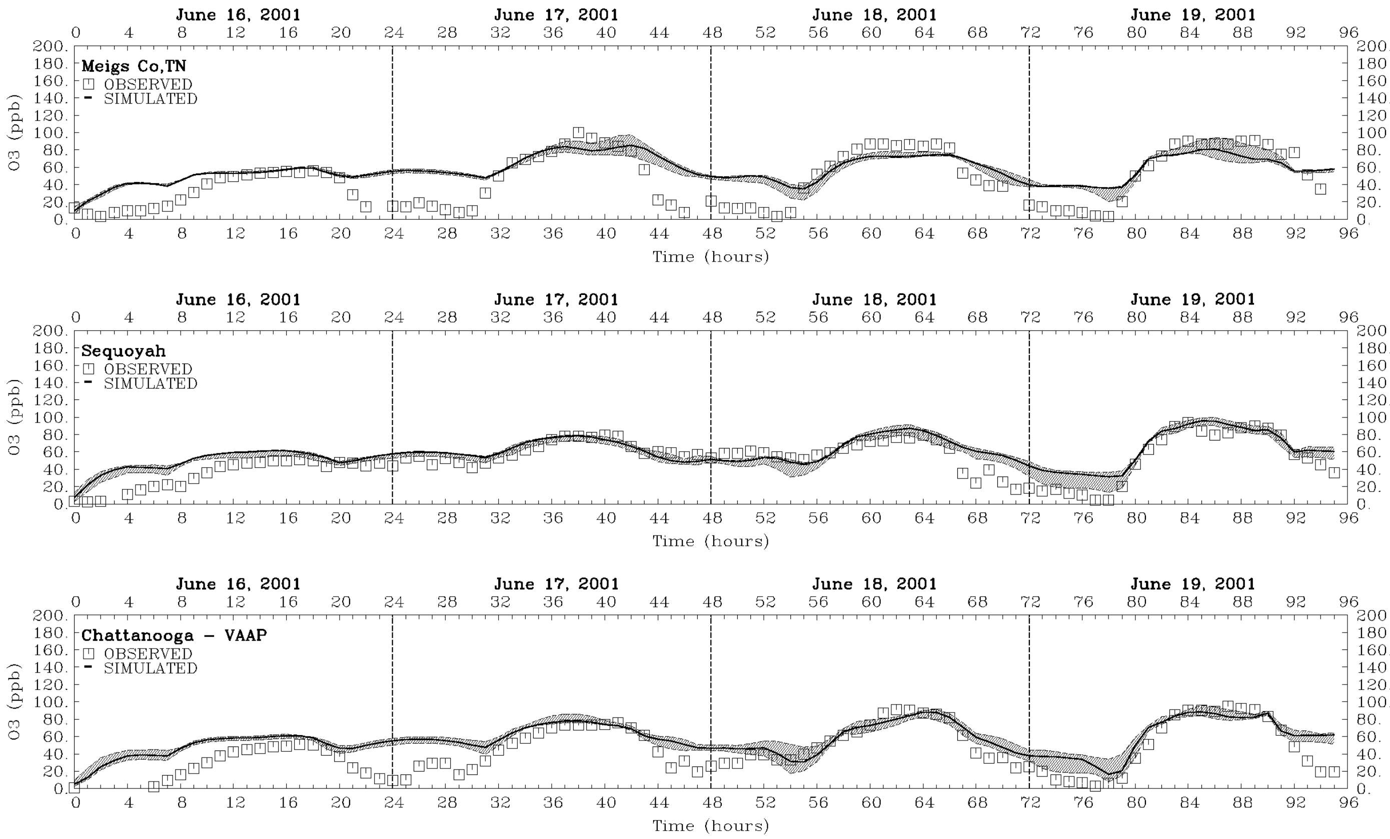


Figure 6-7l.
2001 Episode Time Series: Chattanooga EAC Area,
June 19-22, 2001

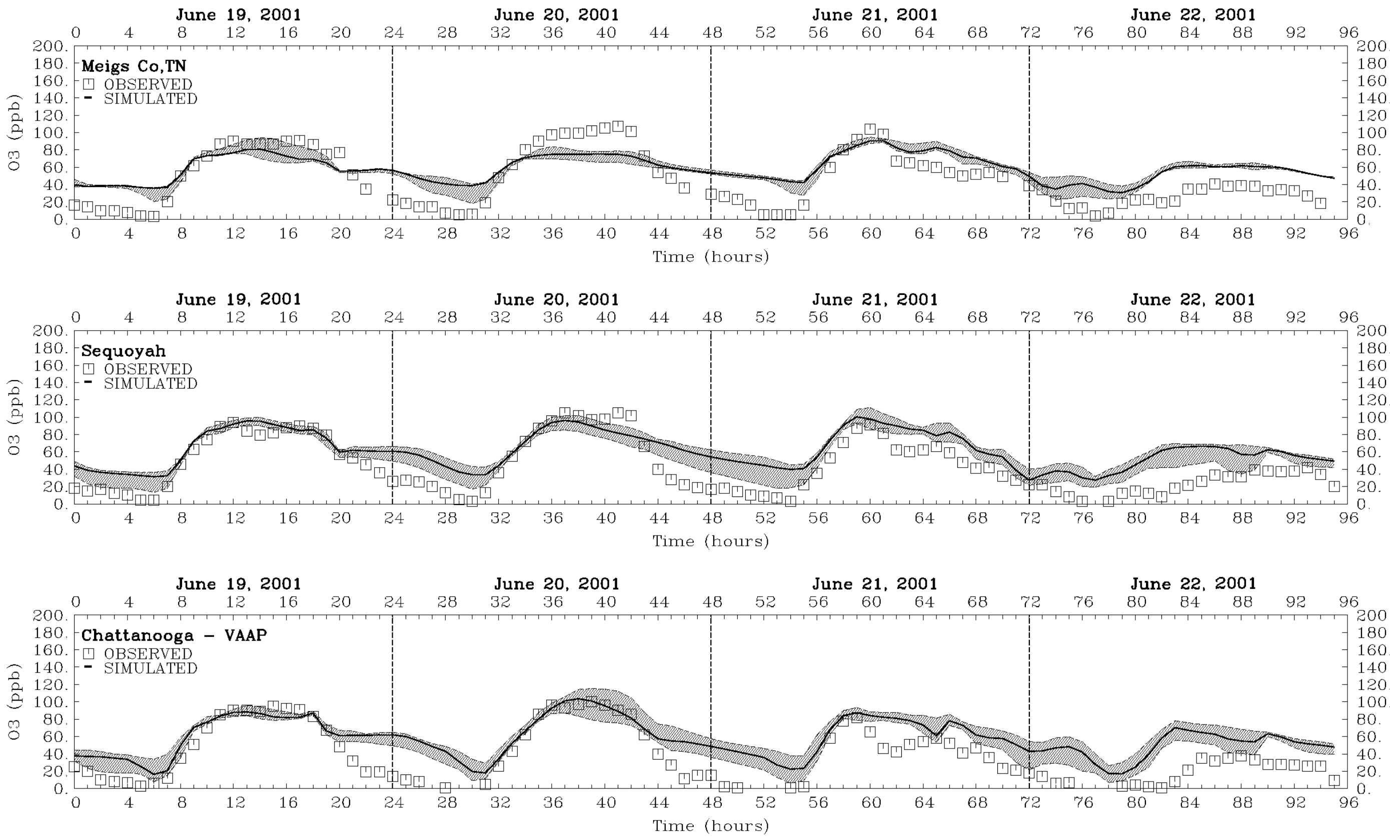
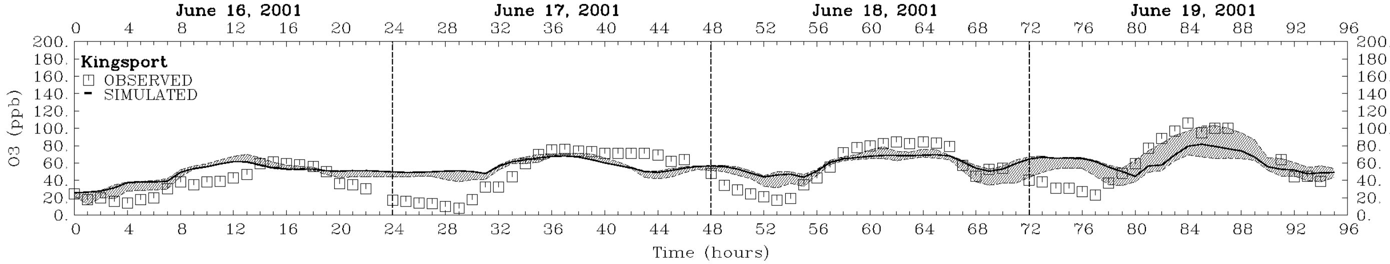


Figure 6-7m.
2001 Episode Time Series: Tri-Cities EAC Area,
June 16-19, 2001



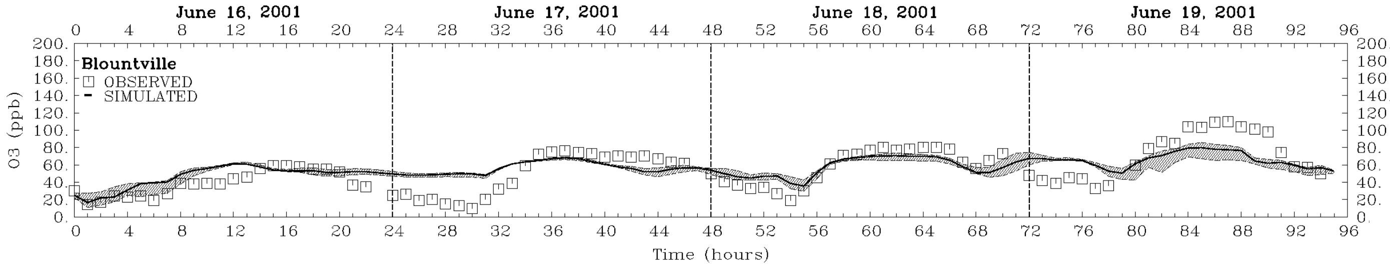
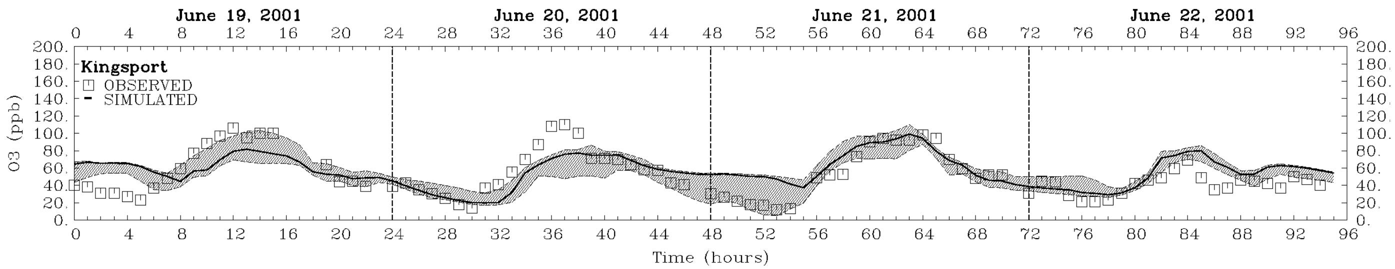


Figure 6-7n.
2001 Episode Time Series: Tri-Cities EAC Area,
June 19-22, 2001



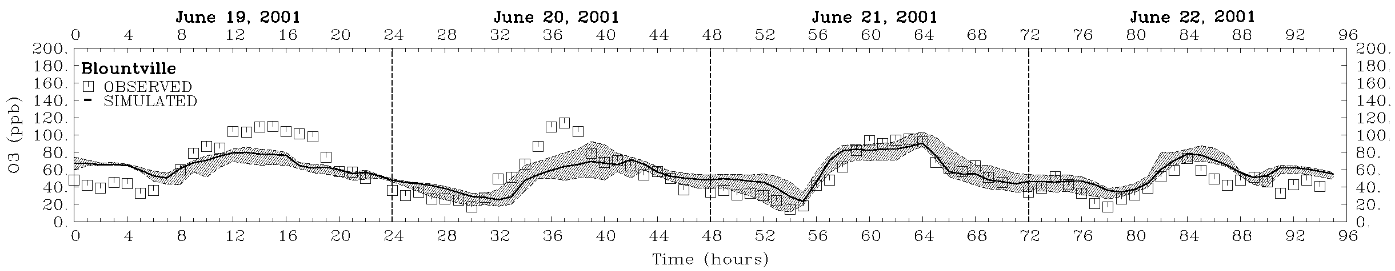


Figure 6-8a.
Scatter Plot: June 16, 2001

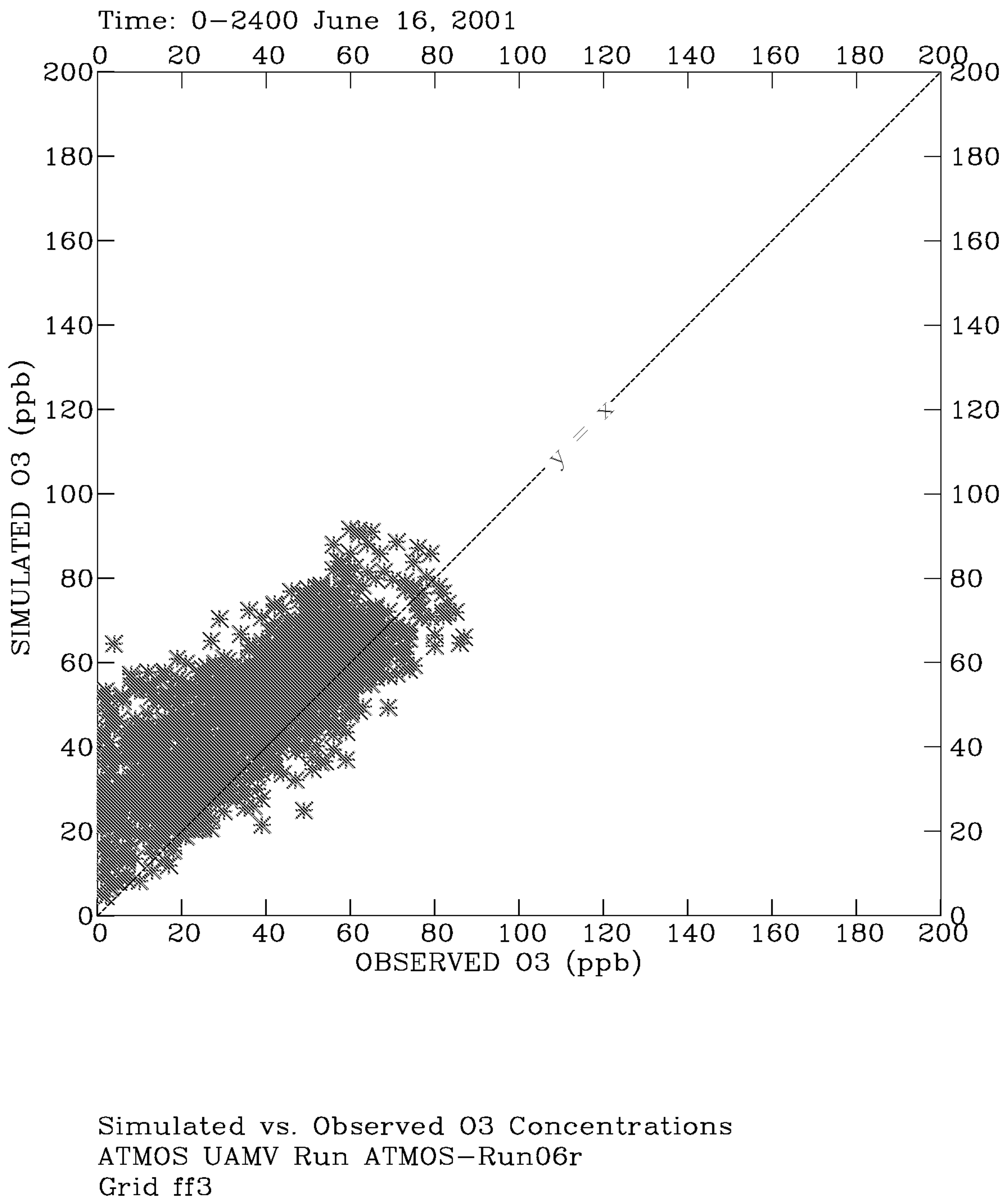
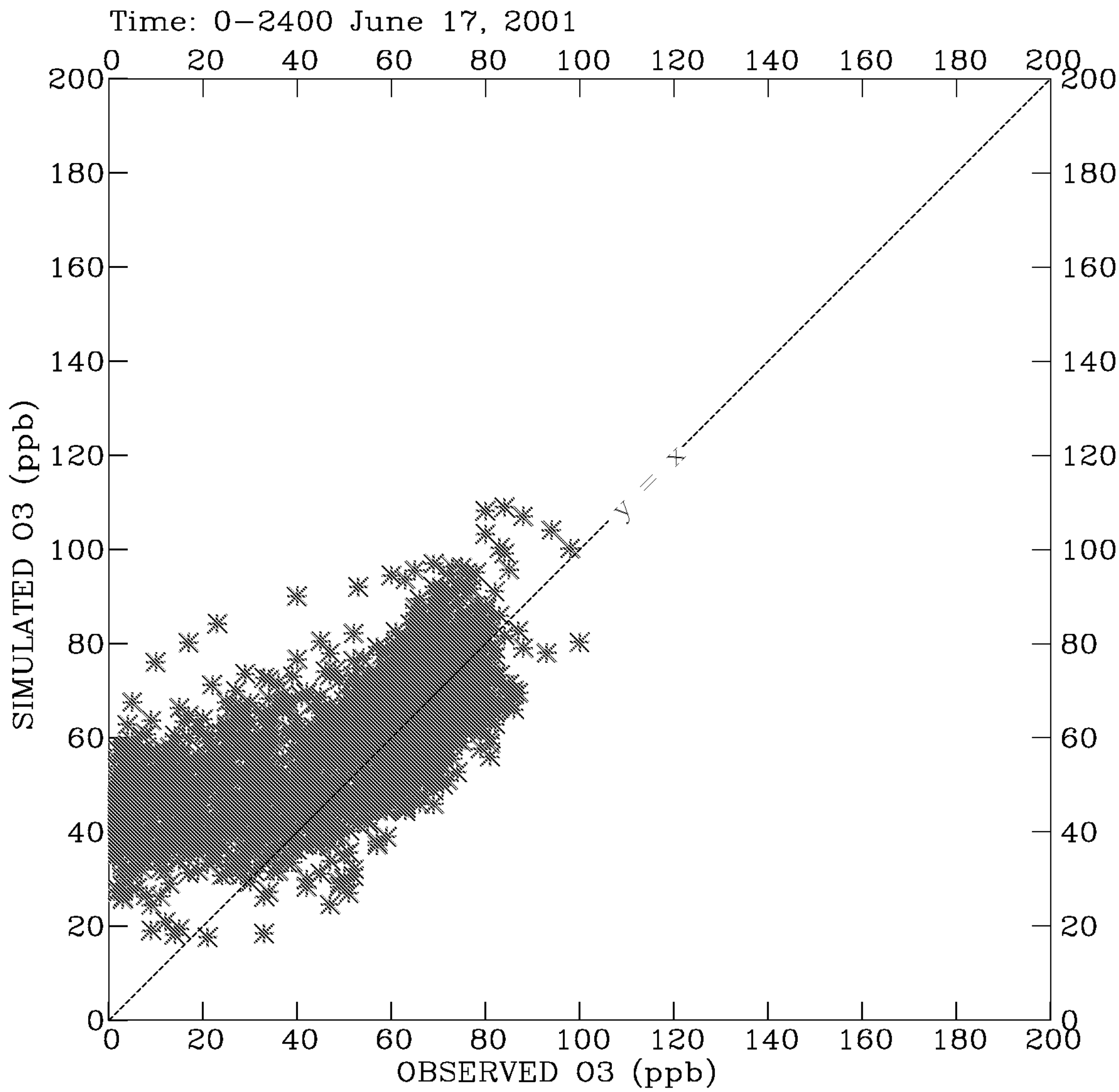
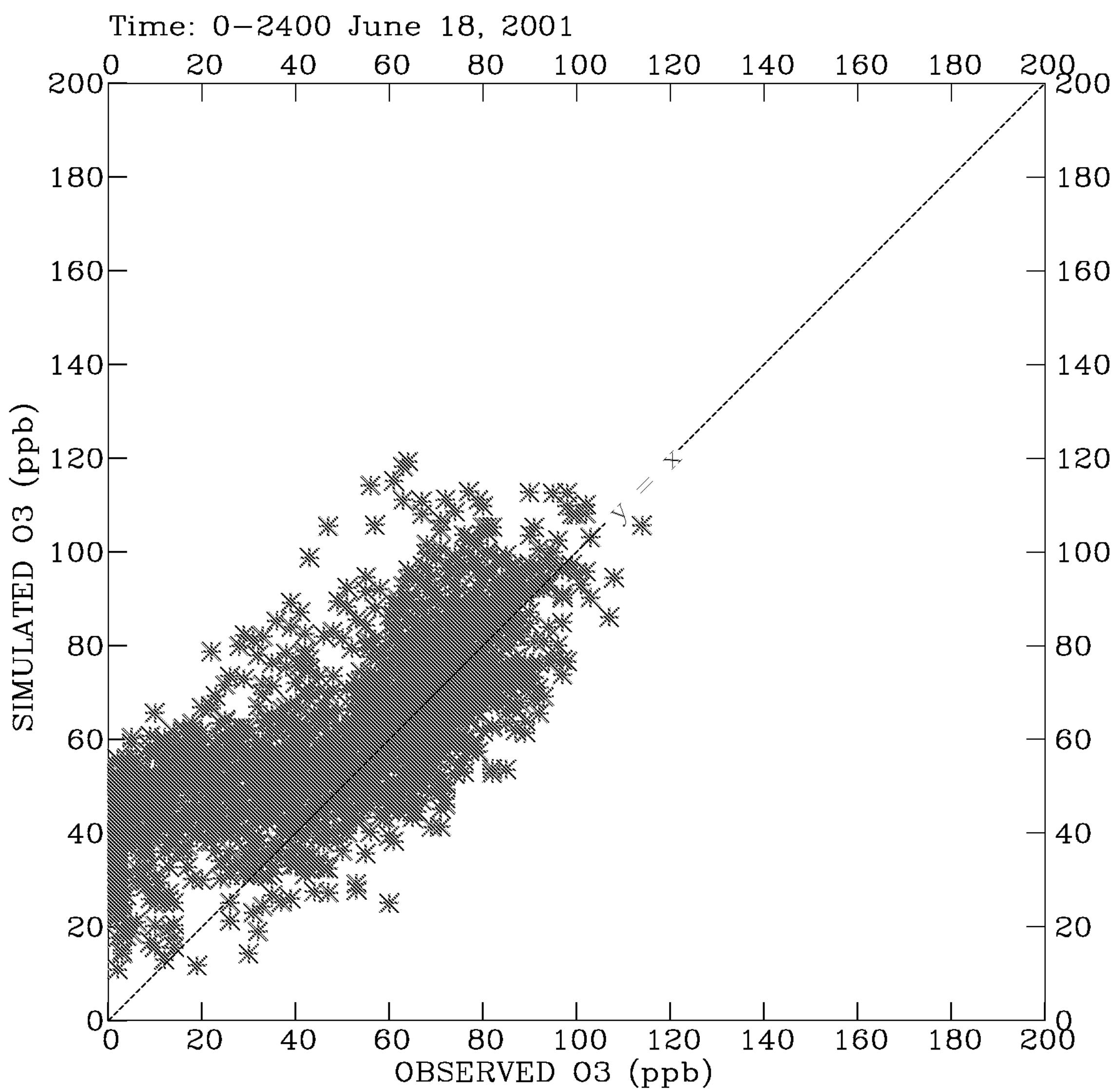


Figure 6-8b.
Scatter Plot: June 17, 2001



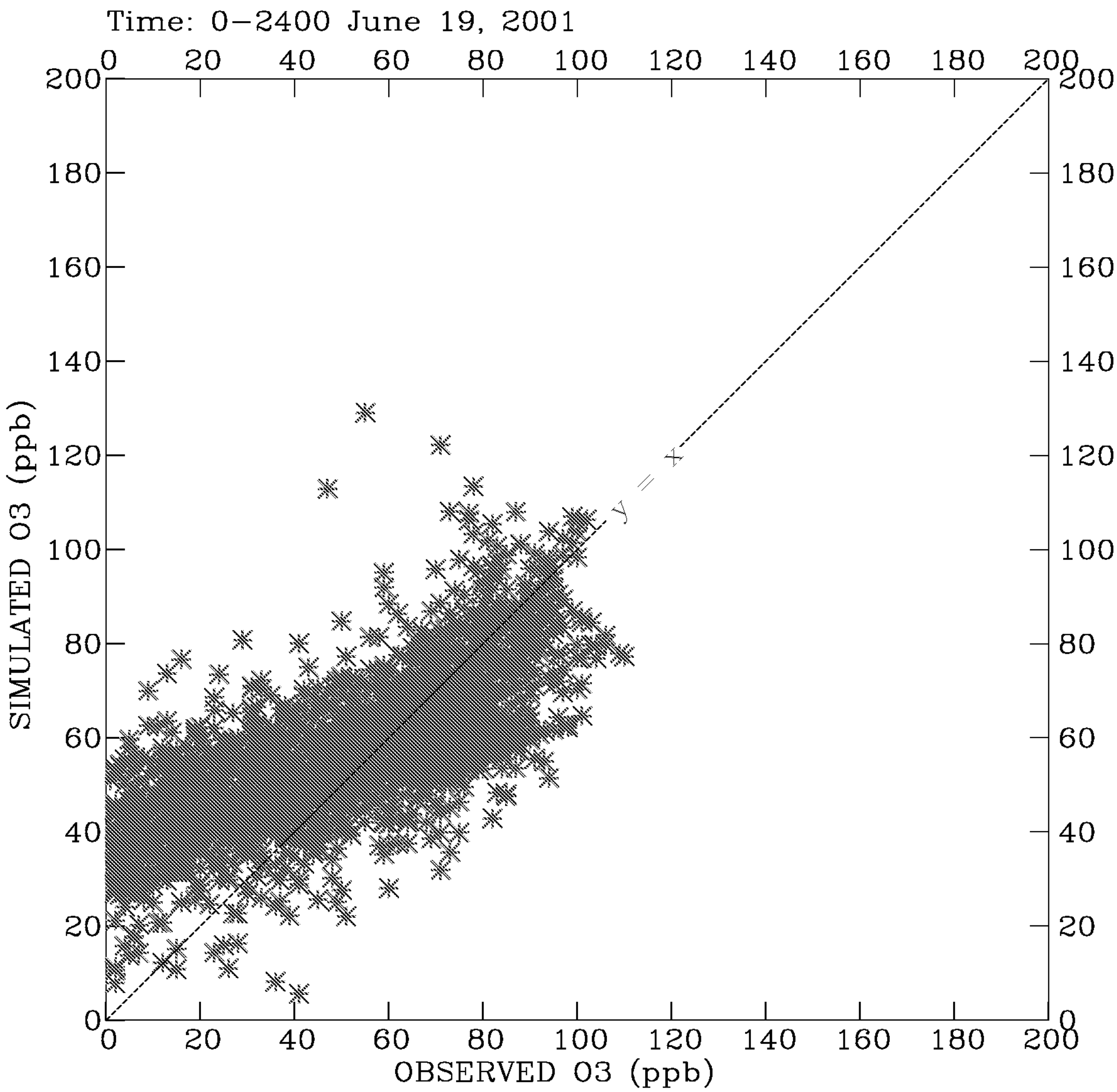
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8c.
Scatter Plot: June 18, 2001



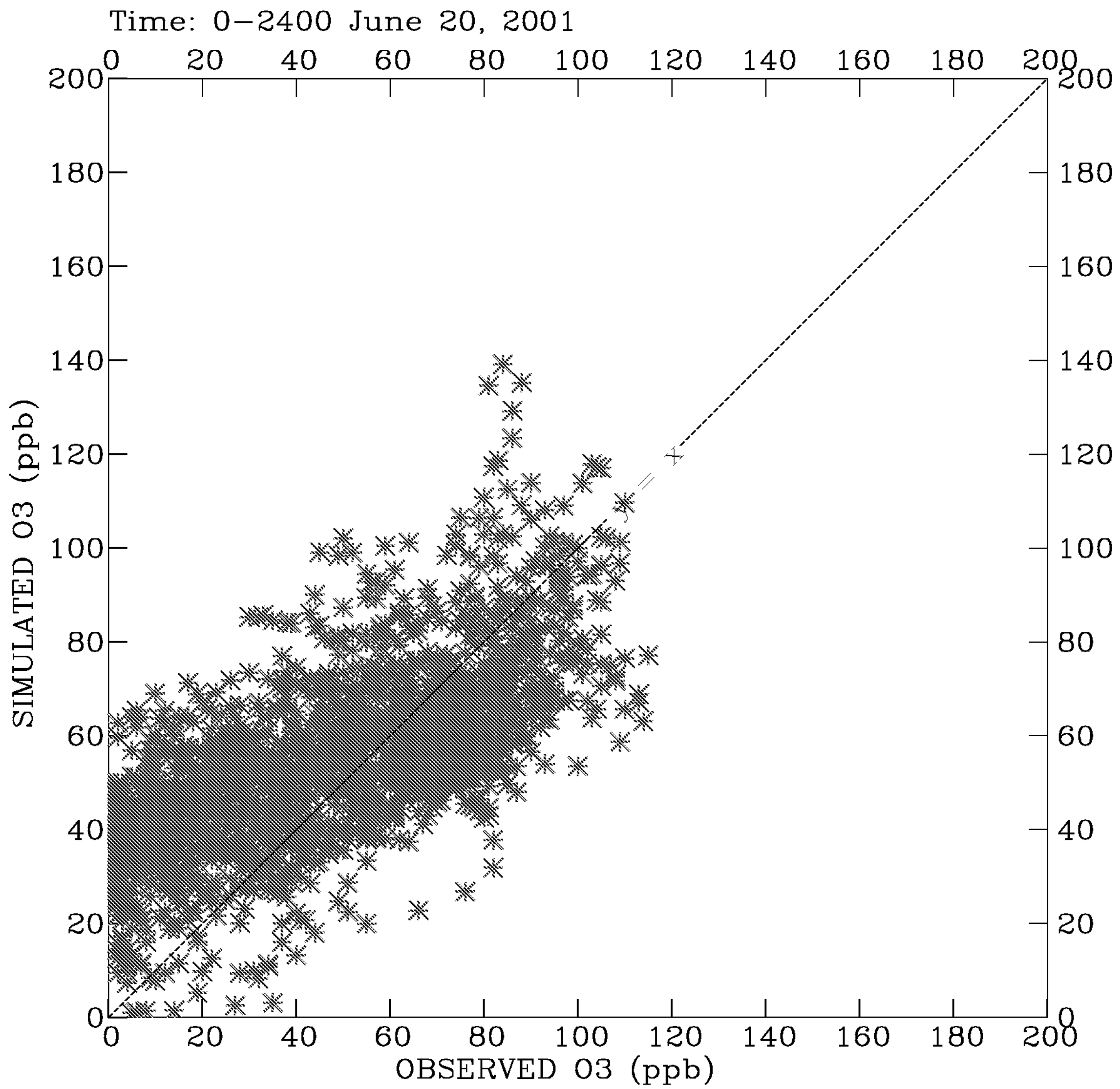
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8d.
Scatter Plot: June 19, 2001



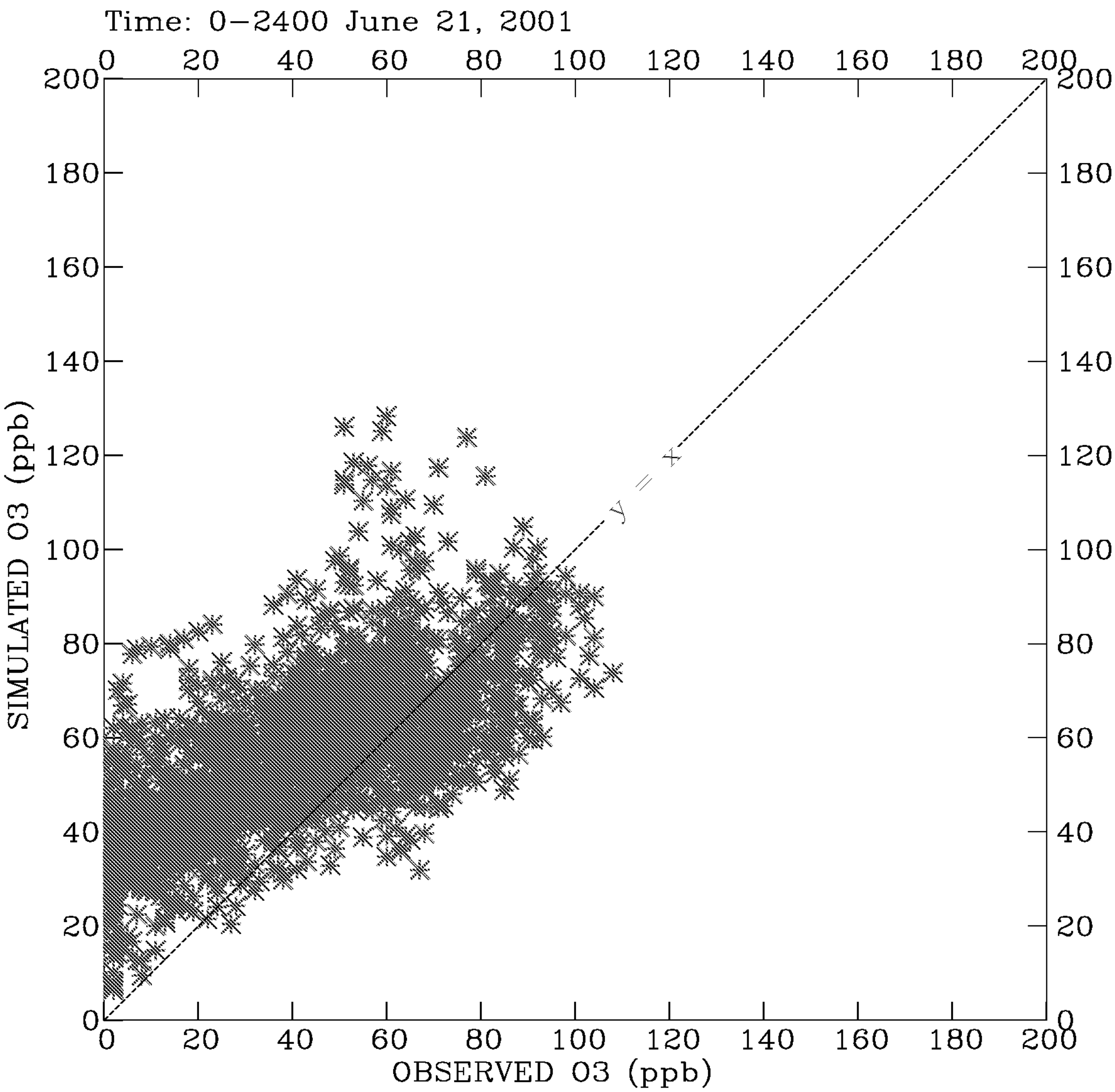
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8e.
Scatter Plot: June 20, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS−Run06r
Grid ff3

Figure 6-8f.
Scatter Plot: June 21, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS-Run06r
Grid ff3

Figure 6-8g.
Scatter Plot: June 22, 2001

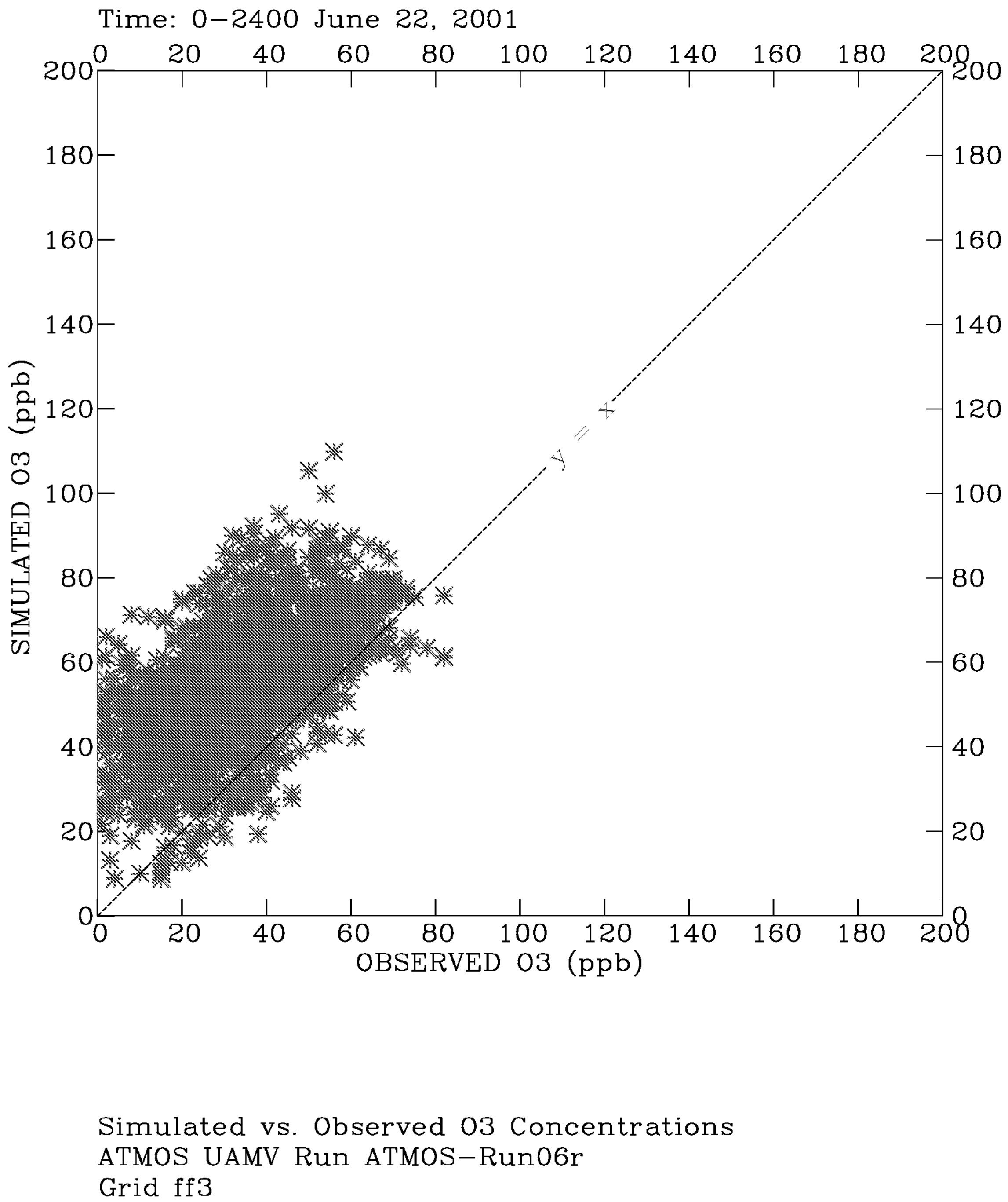


Figure 6-9a.
Daily Maximum 1-Hour Ozone, Grid 1,
July 4, 2002

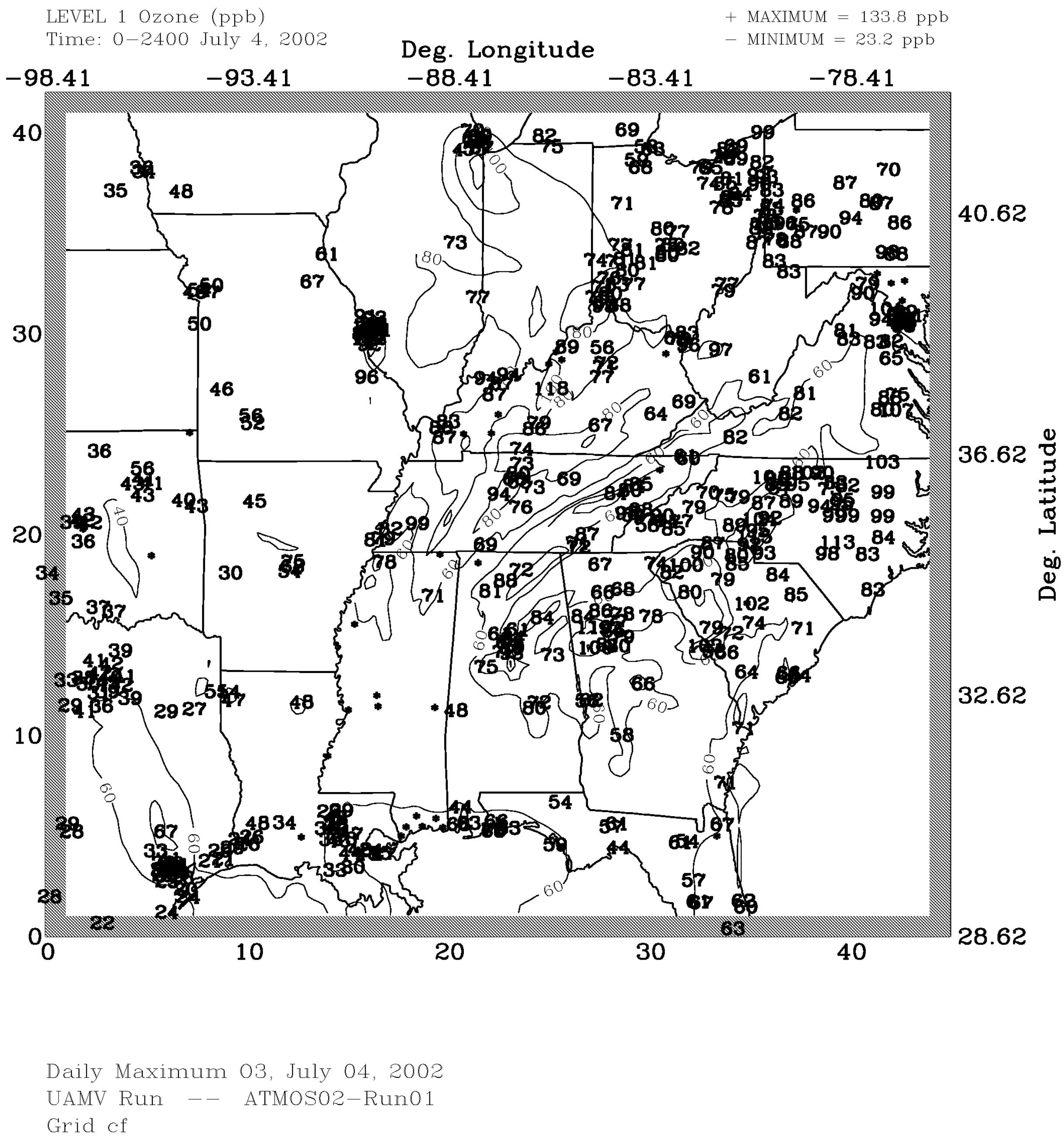


**Figure 6-9b.
Daily Maximum 1-Hour Ozone, Grid 1,
July 5, 2002**

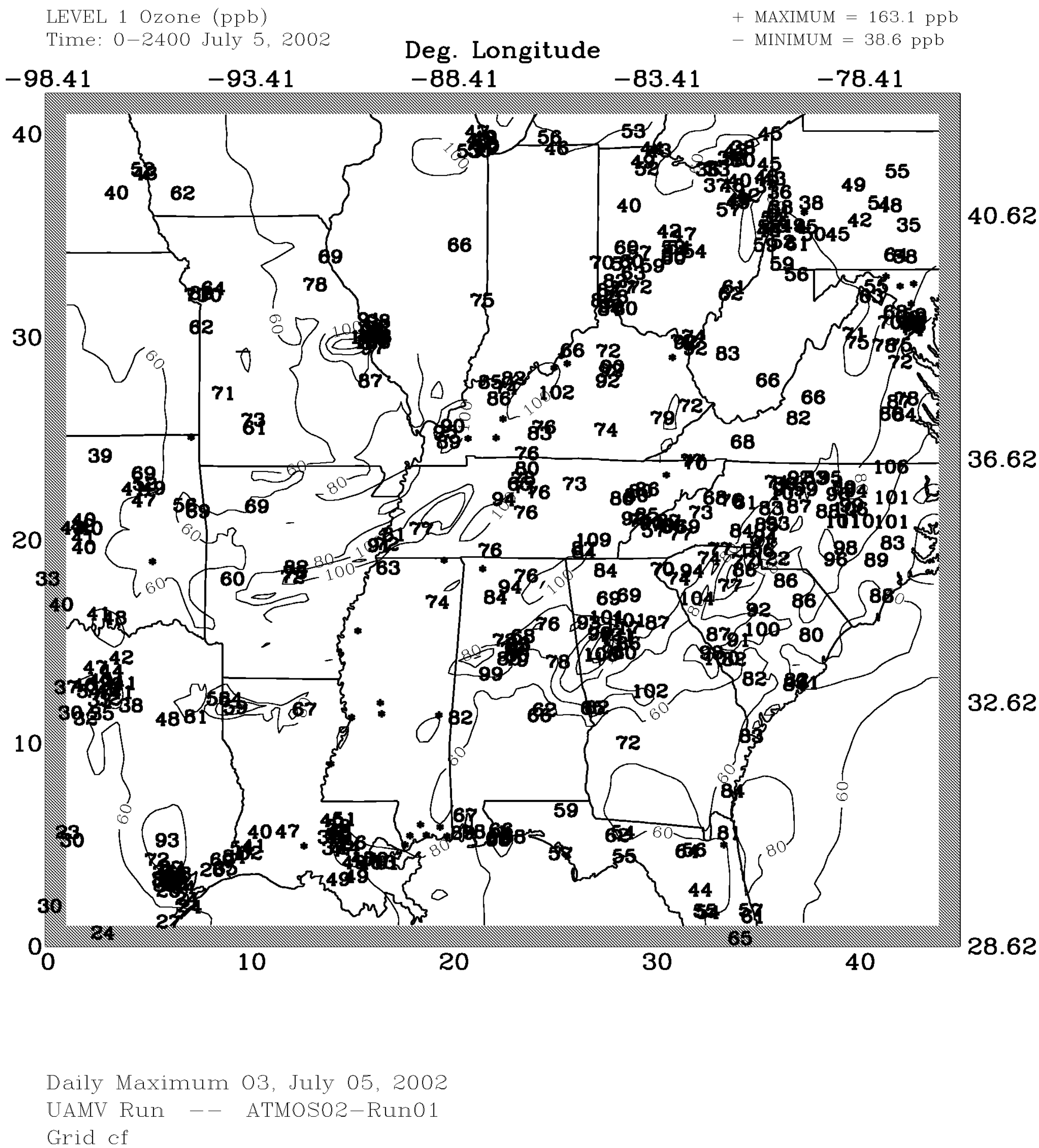


Figure 6-9c.
Daily Maximum 1-Hour Ozone, Grid 1,
July 6, 2002

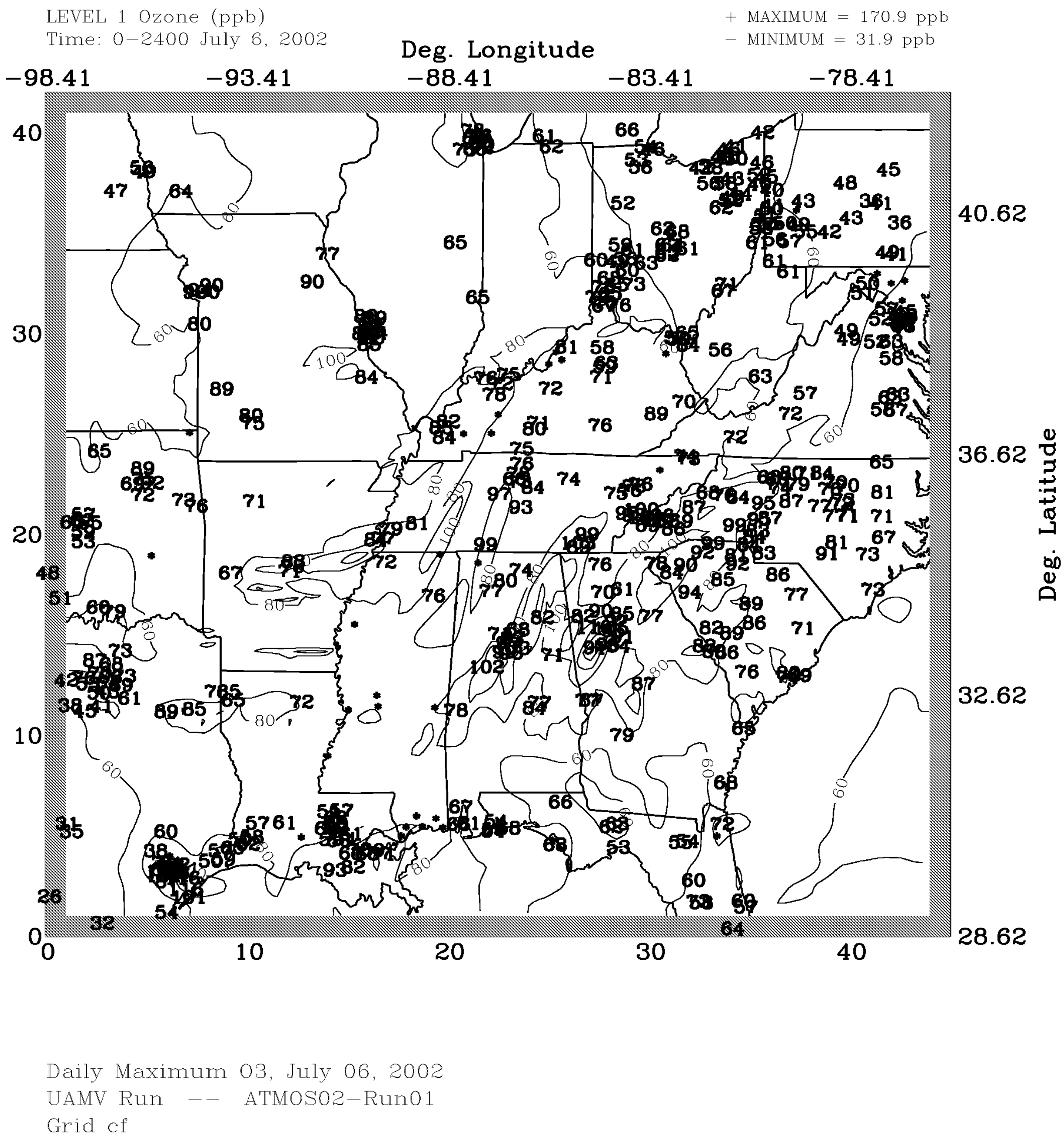


Figure 6-9d.
Daily Maximum 1-Hour Ozone, Grid 1,
July 7, 2002

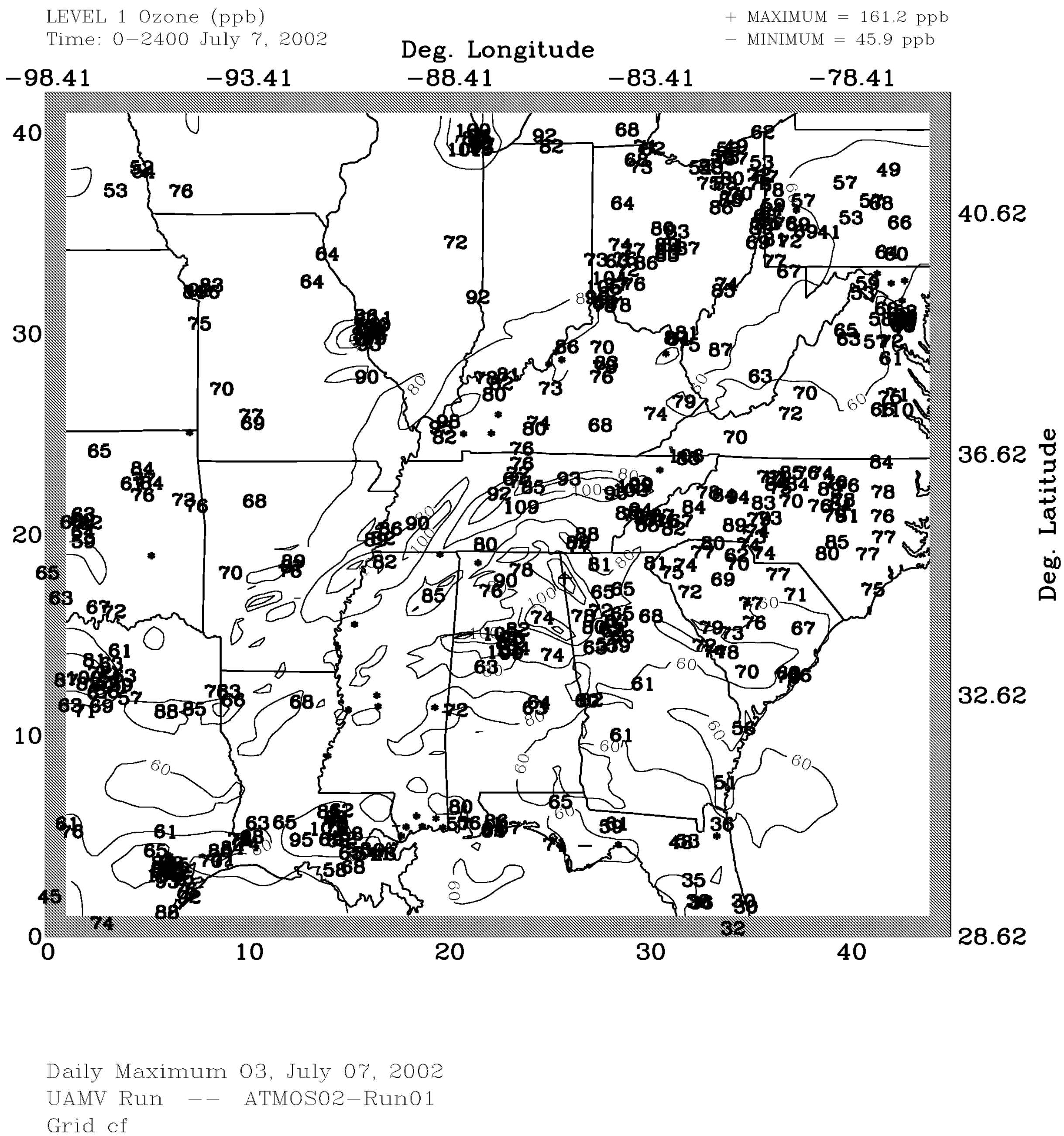


Figure 6-9e.
Daily Maximum 1-Hour Ozone, Grid 1,
July 8, 2002

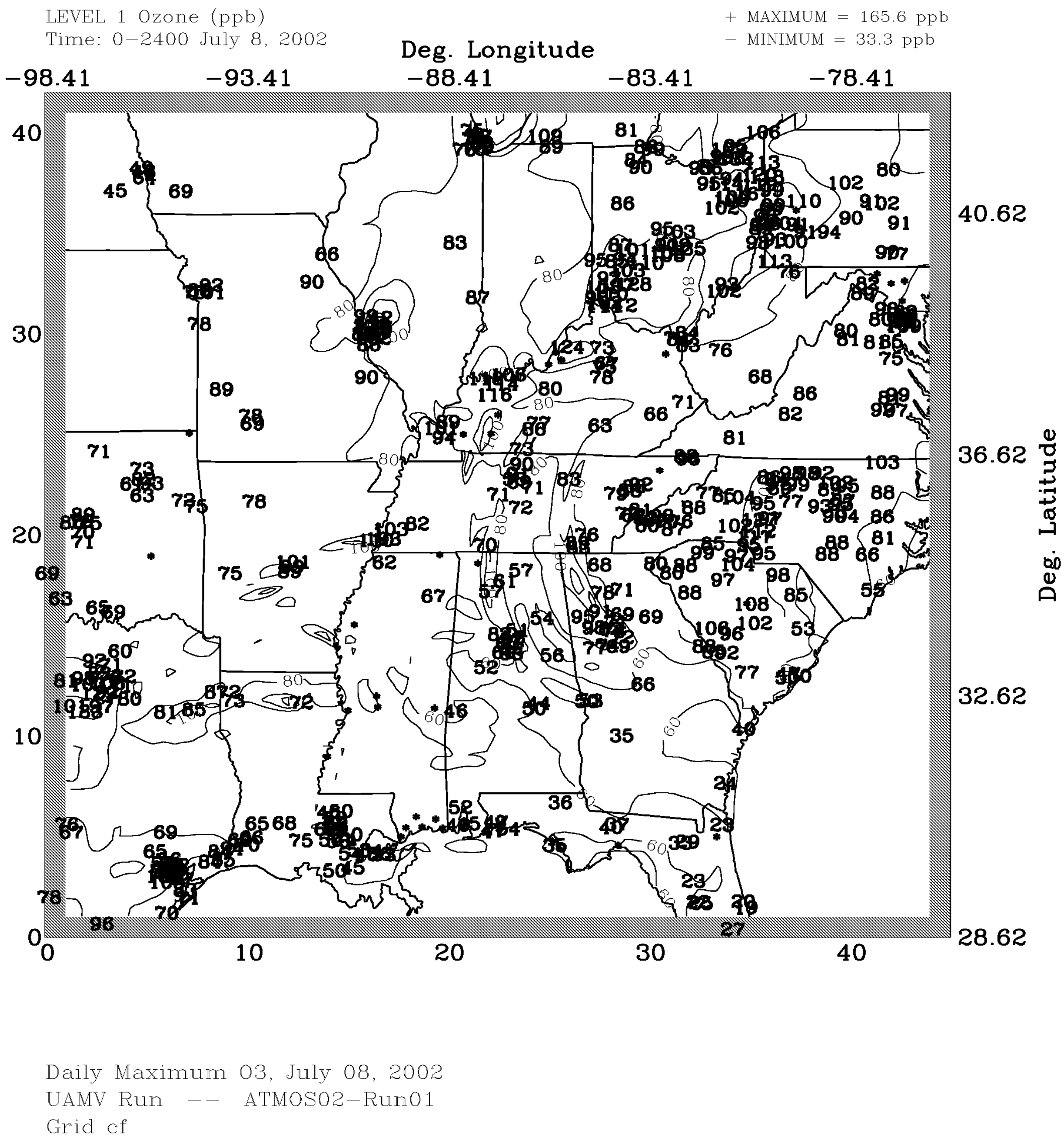


Figure 6-9f.
Daily Maximum 1-Hour Ozone, Grid 1,
July 9, 2002

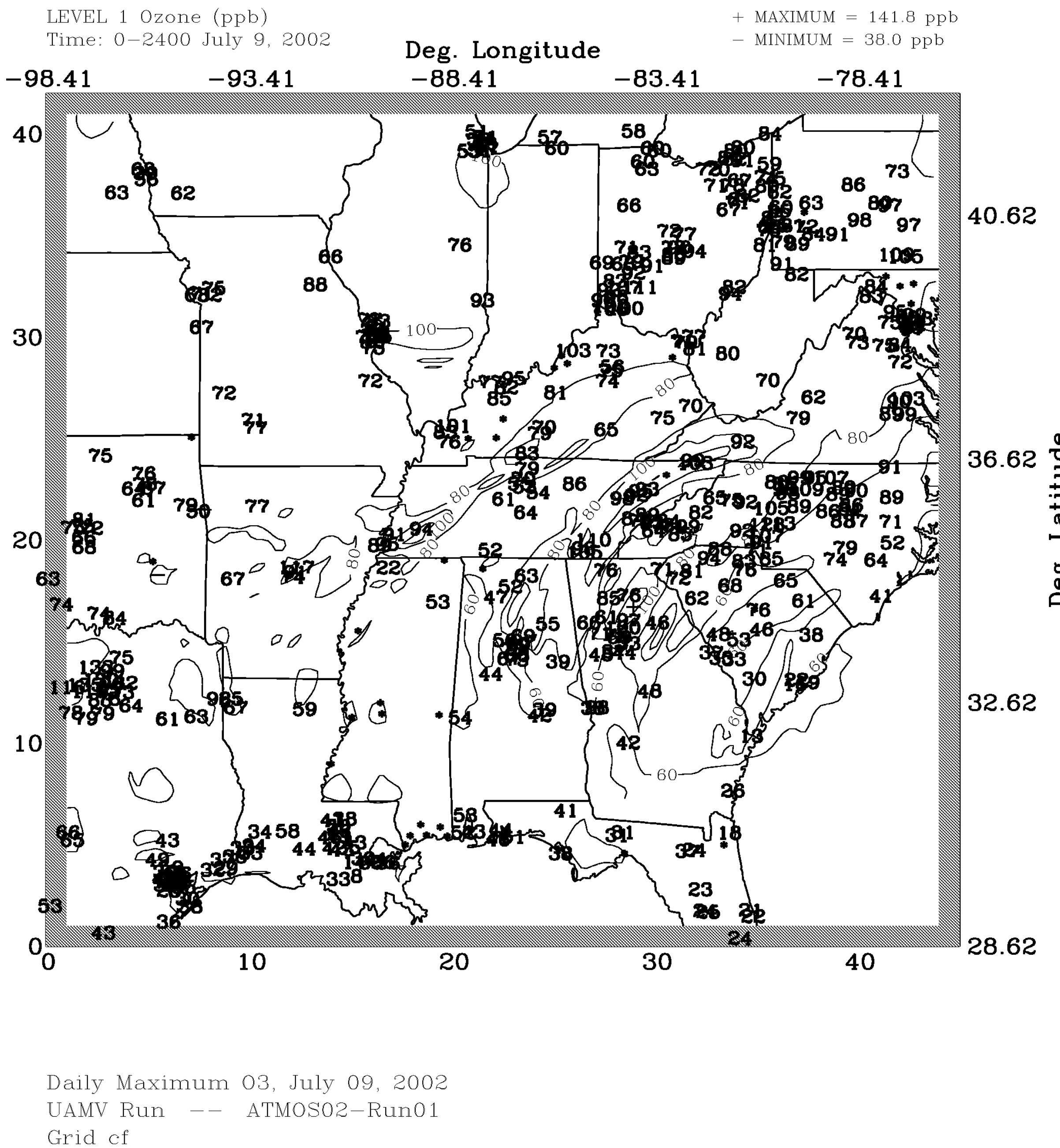


Figure 6-9g.
Daily Maximum 1-Hour Ozone, Grid 1,
July 10, 2002

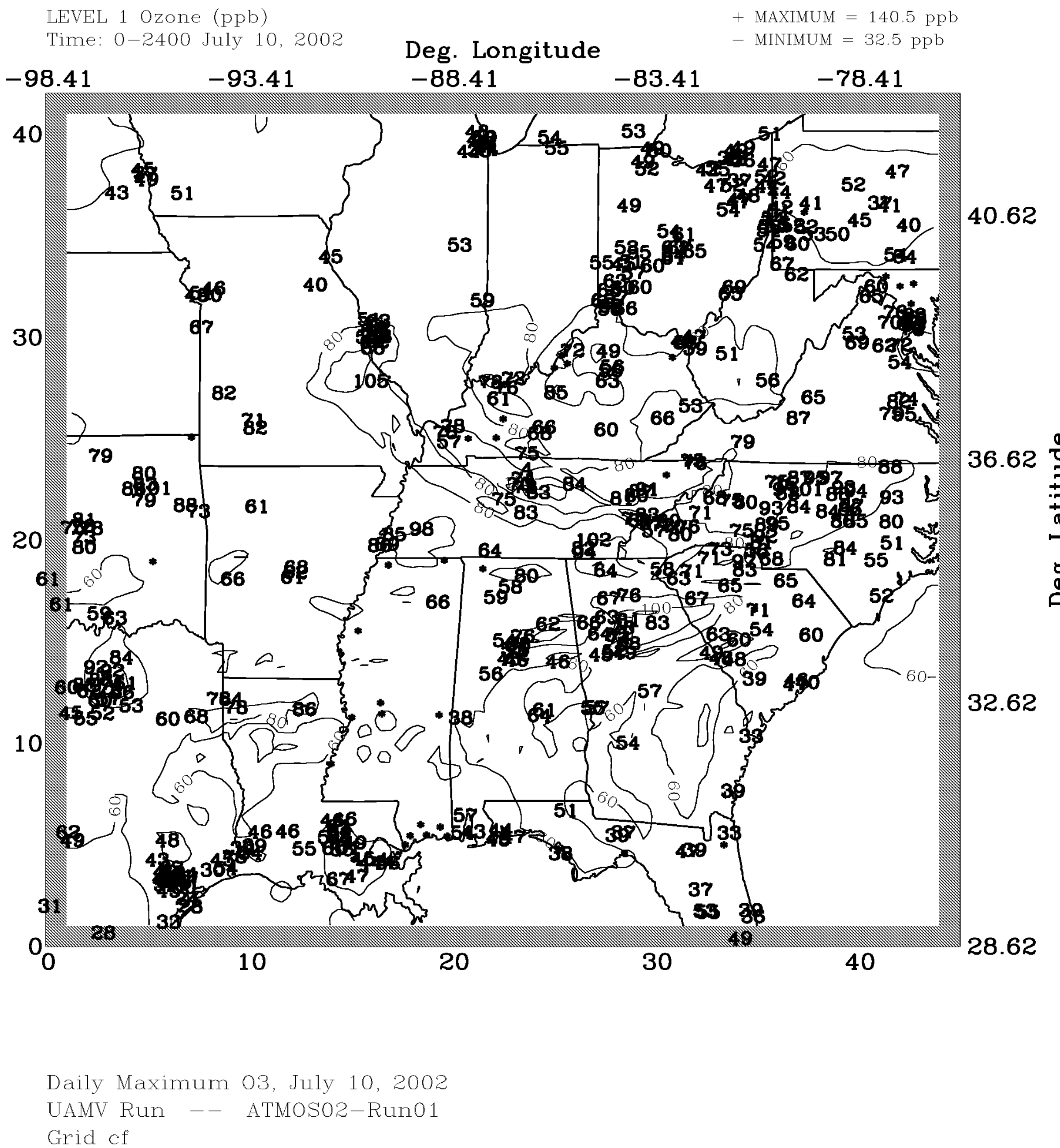


Figure 6-10a.
Daily Maximum 1-Hour Ozone, Grid 3
July 4, 2002

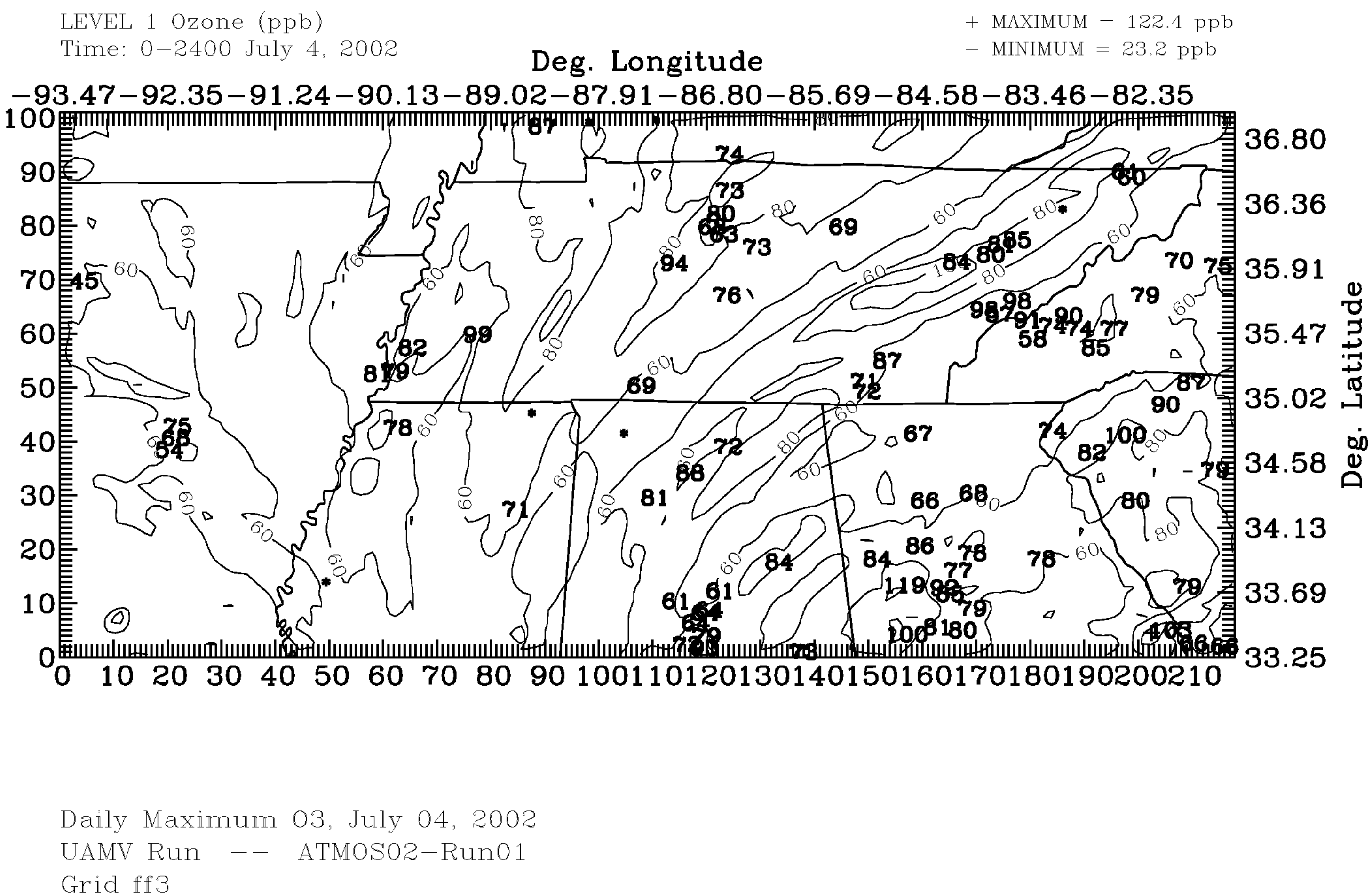


Figure 6-10b.
Daily Maximum 1-Hour Ozone, Grid 3
July 5, 2002

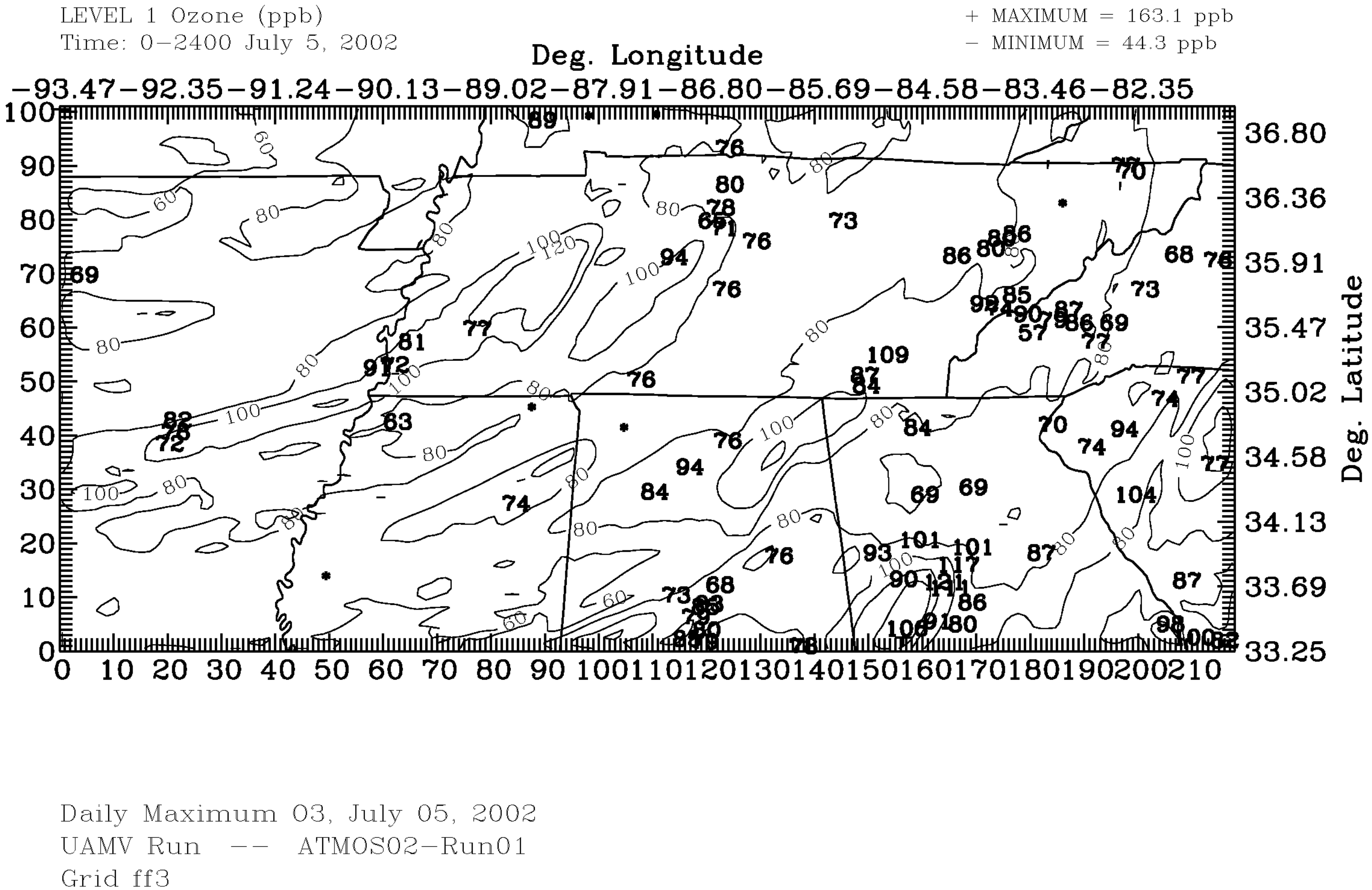


Figure 6-10c.
Daily Maximum 1-Hour Ozone, Grid 3,
July 6, 2002

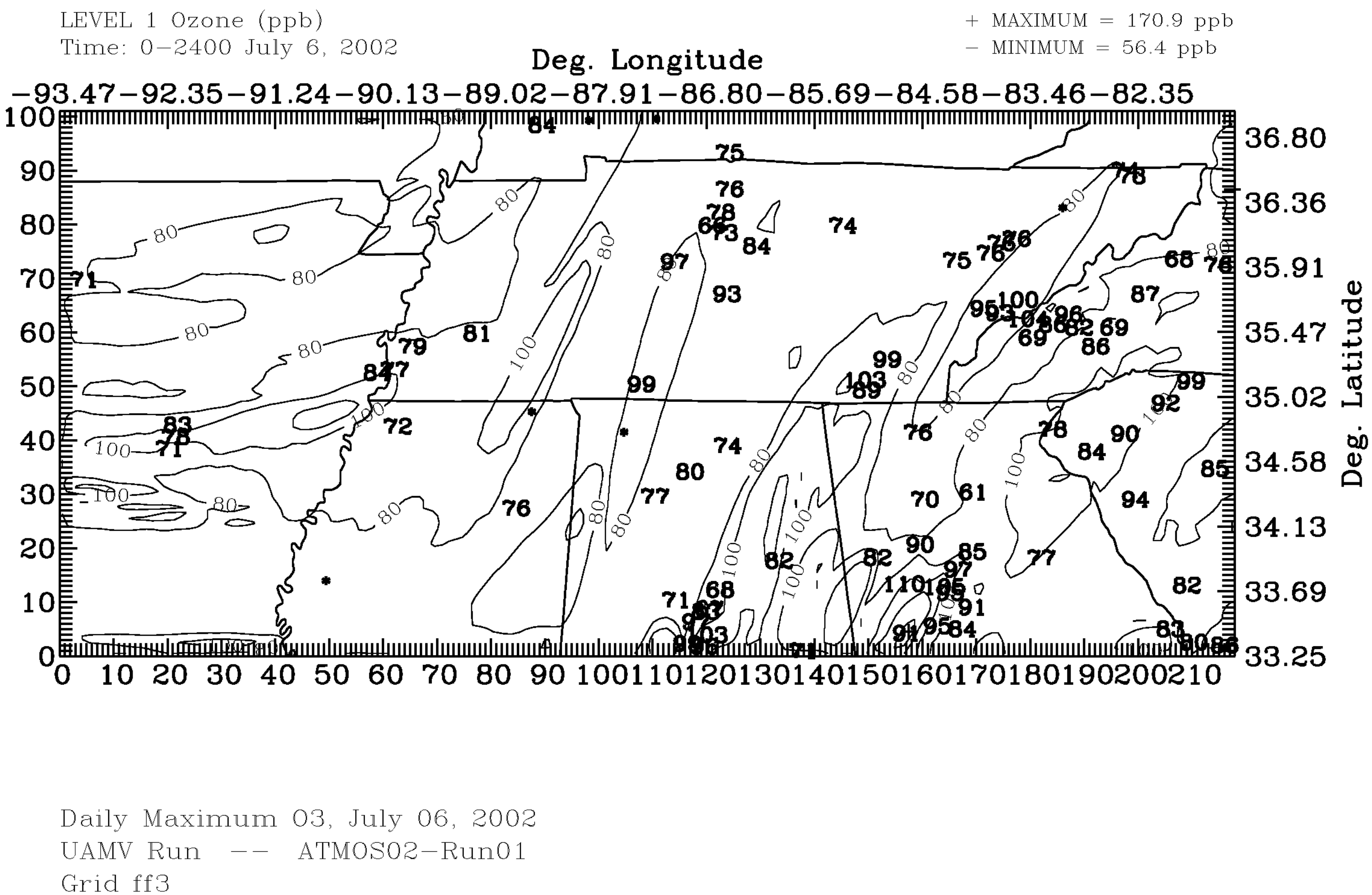


Figure 6-10d.
Daily Maximum 1-Hour Ozone, Grid 3,
July 7, 2002

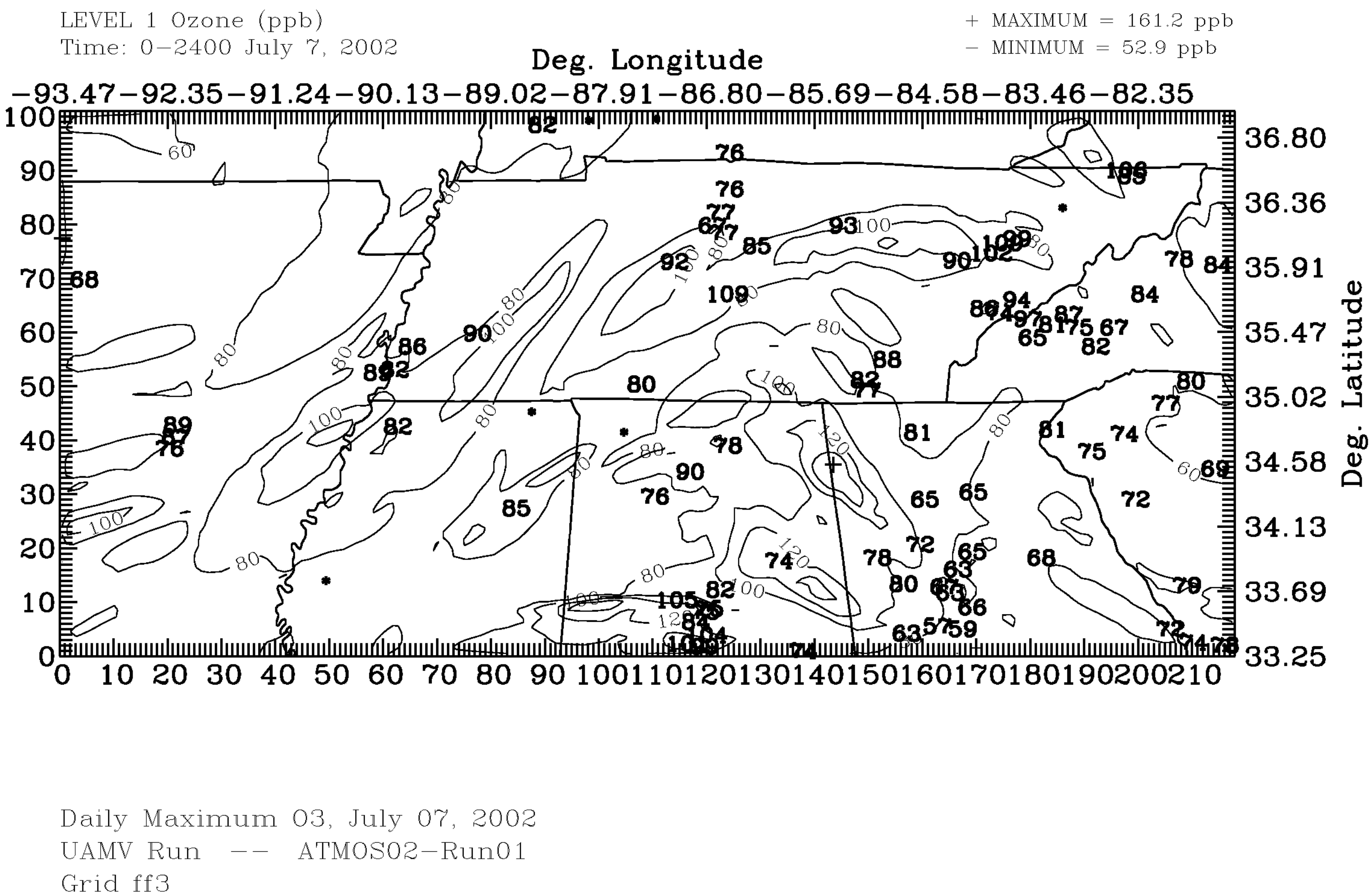


Figure 6-10e.
Daily Maximum 1-Hour Ozone, Grid 3,
July 8, 2002

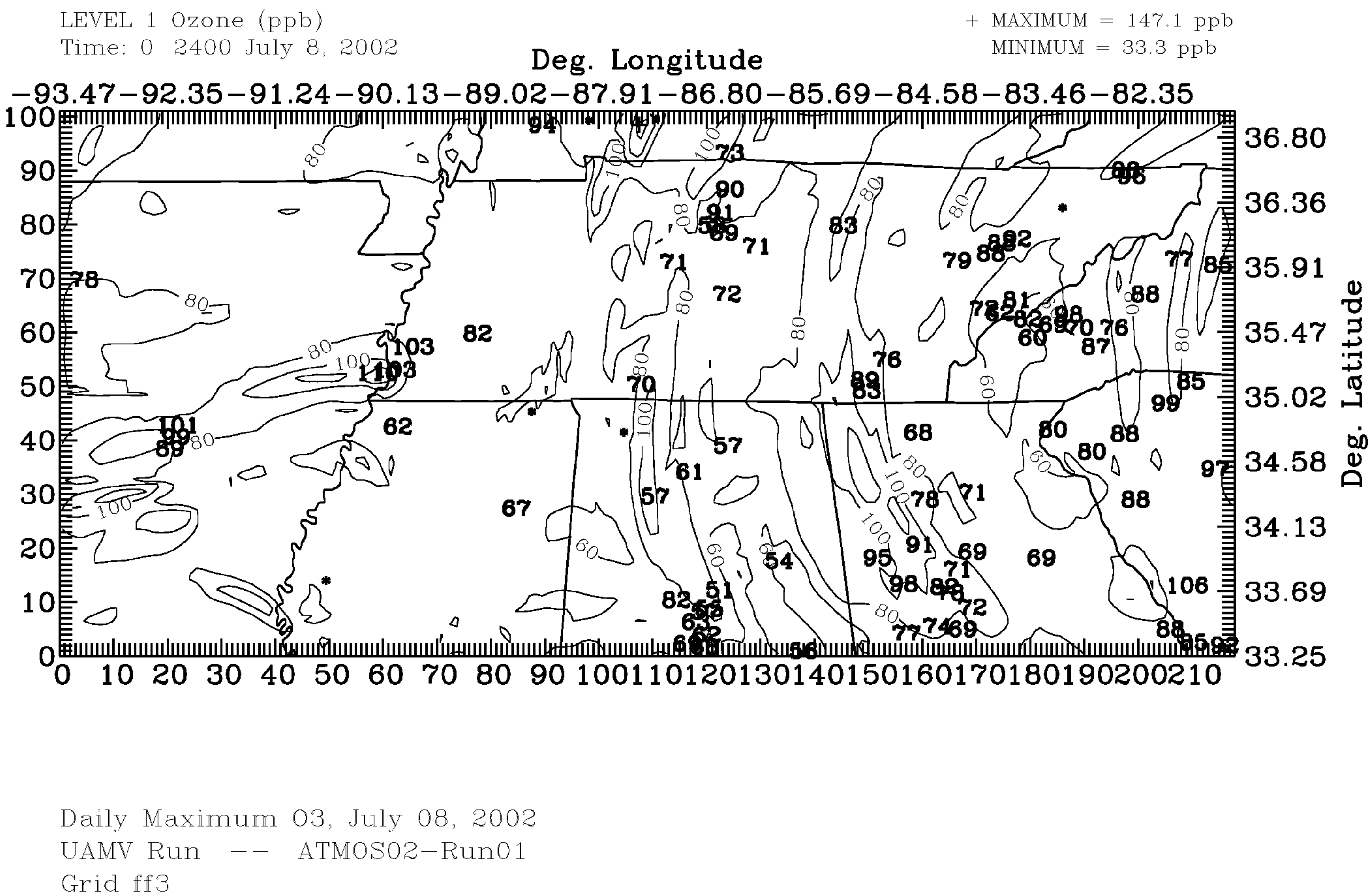


Figure 6-10f.
Daily Maximum 1-Hour Ozone, Grid 3,
July 9, 2002

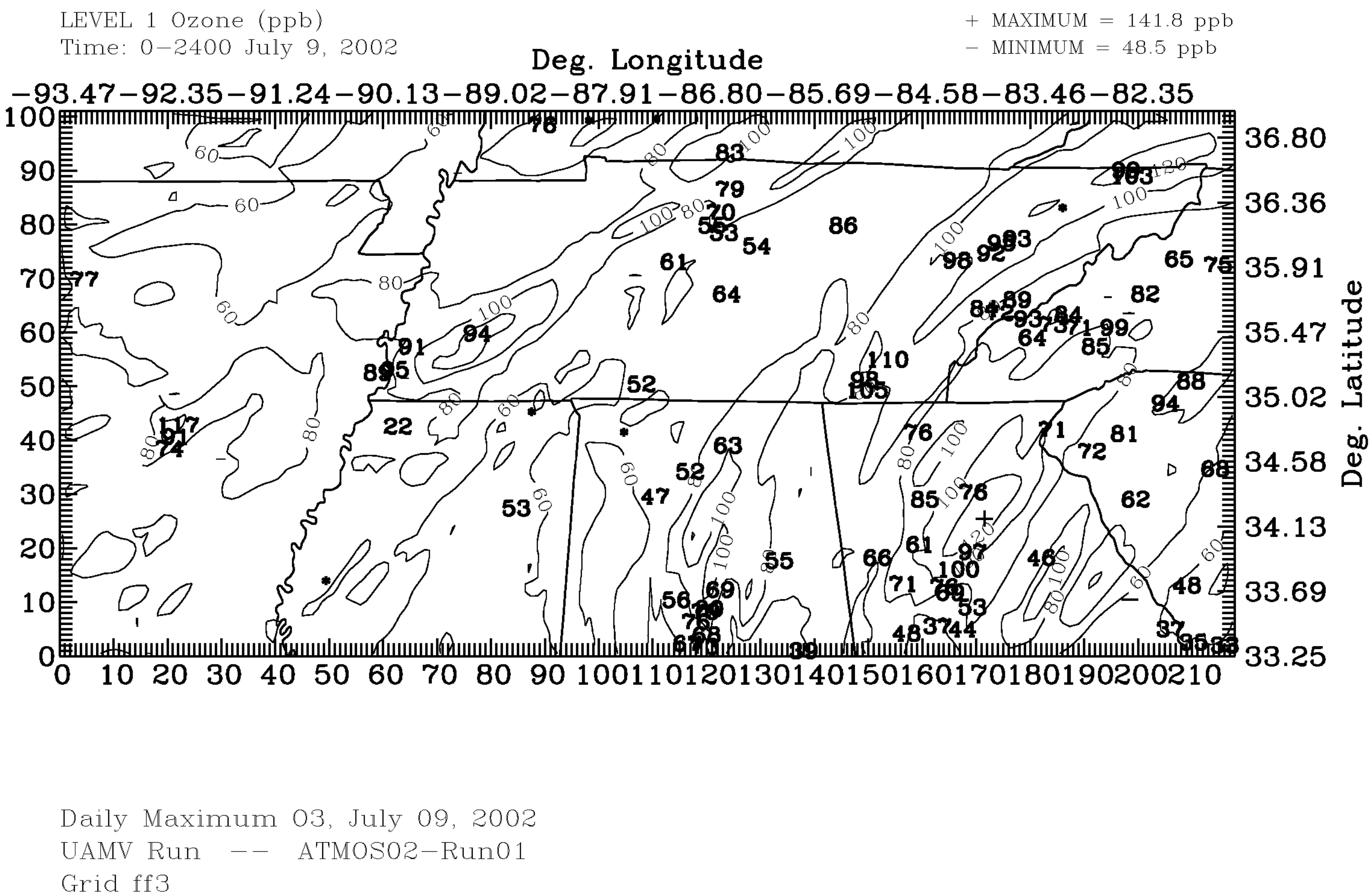
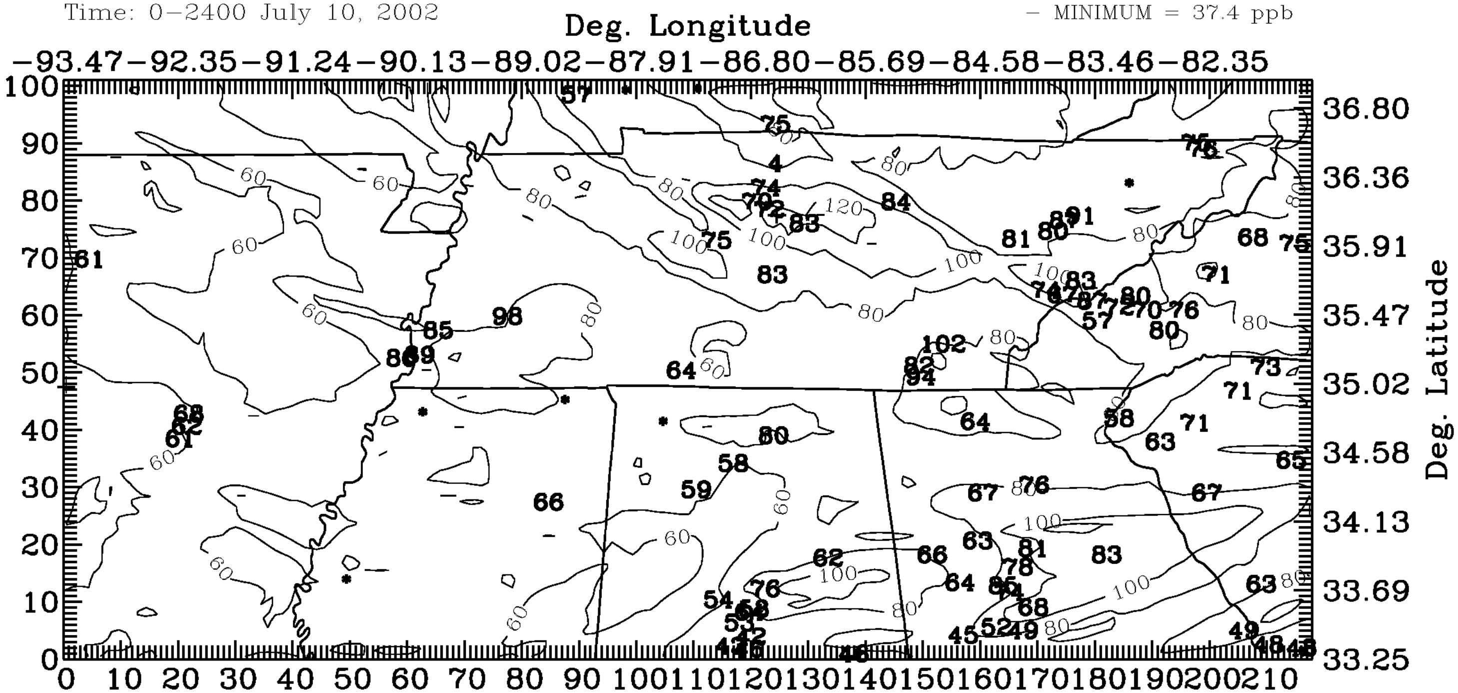


Figure 6-10g.
Daily Maximum 1-Hour Ozone, Grid 3,
July 10, 2002

LEVEL 1 Ozone (ppb)
Time: 0−2400 July 10, 2002

+ MAXIMUM = 140.5 ppb
− MINIMUM = 37.4 ppb



Daily Maximum O3, July 10, 2002
UAMV Run −− ATMOS02−Run01
Grid ff3

Figure 6-11a.
2001 Episode Time Series: Memphis EAC Area,
July 4-7, 2002

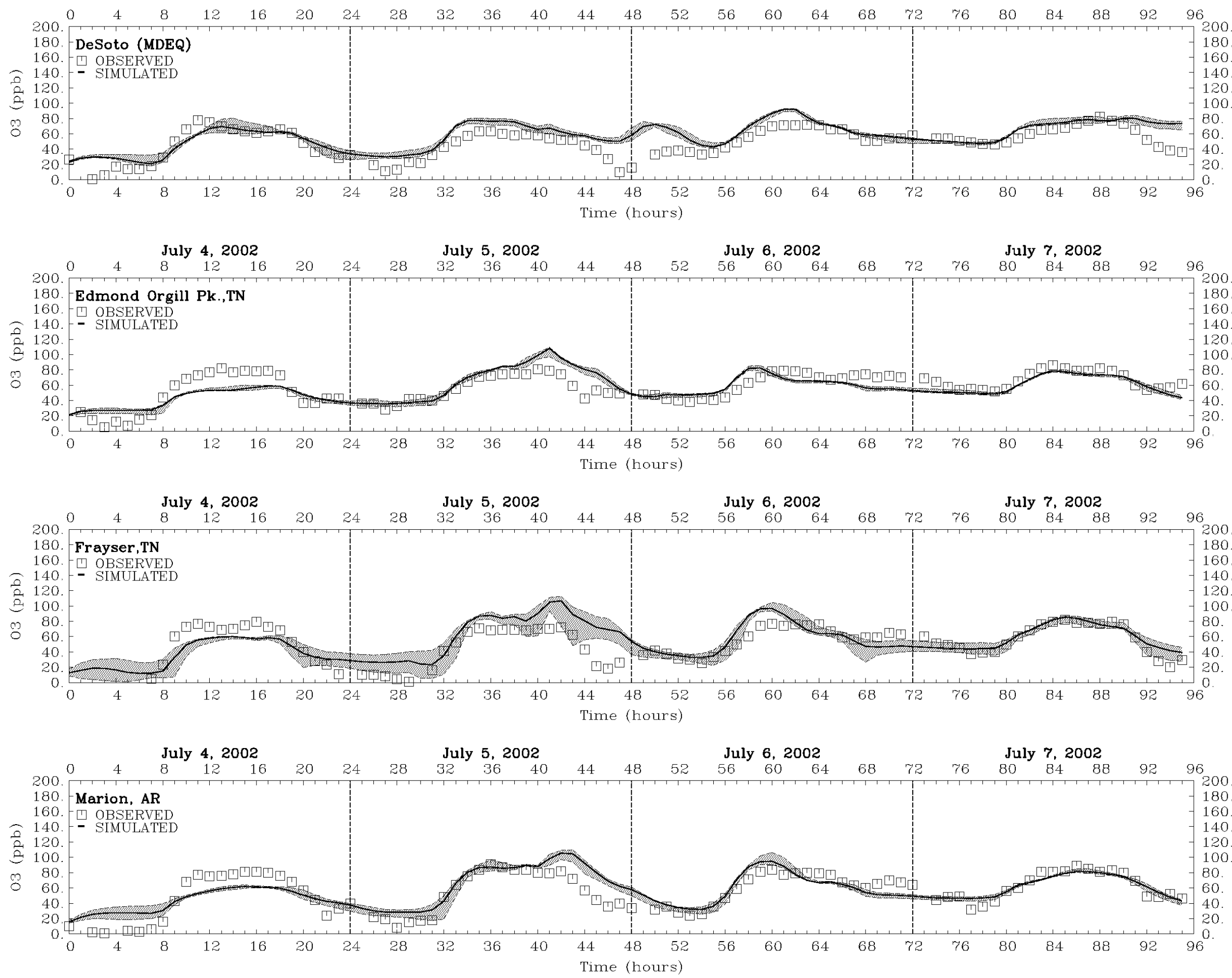


Figure 6-11b.
2001 Episode Time Series: Memphis EAC Area,
July 7-10, 2002

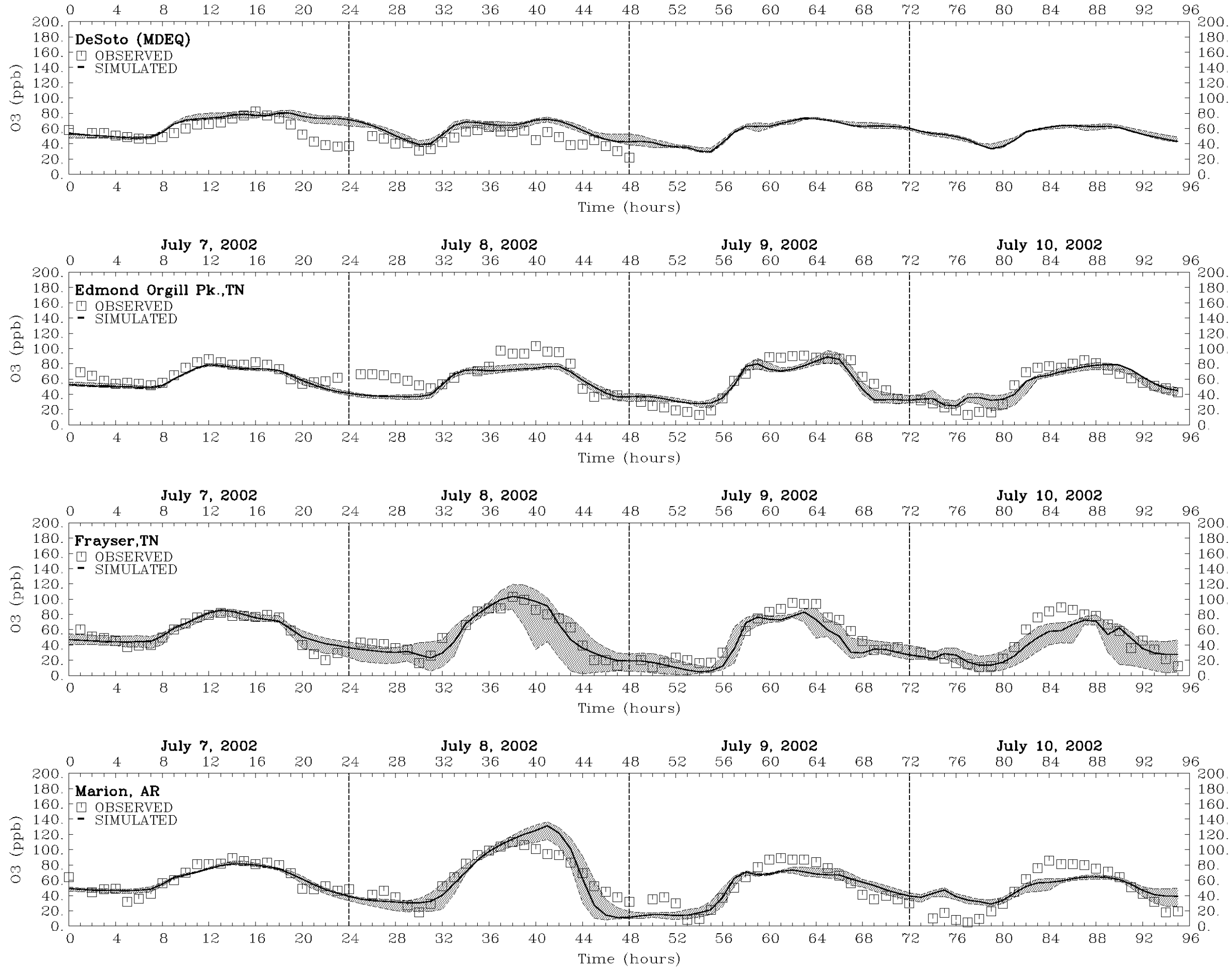


Figure 6-11c.
2001 Episode Time Series: Nashville EAC Area,
July 4-7, 2002

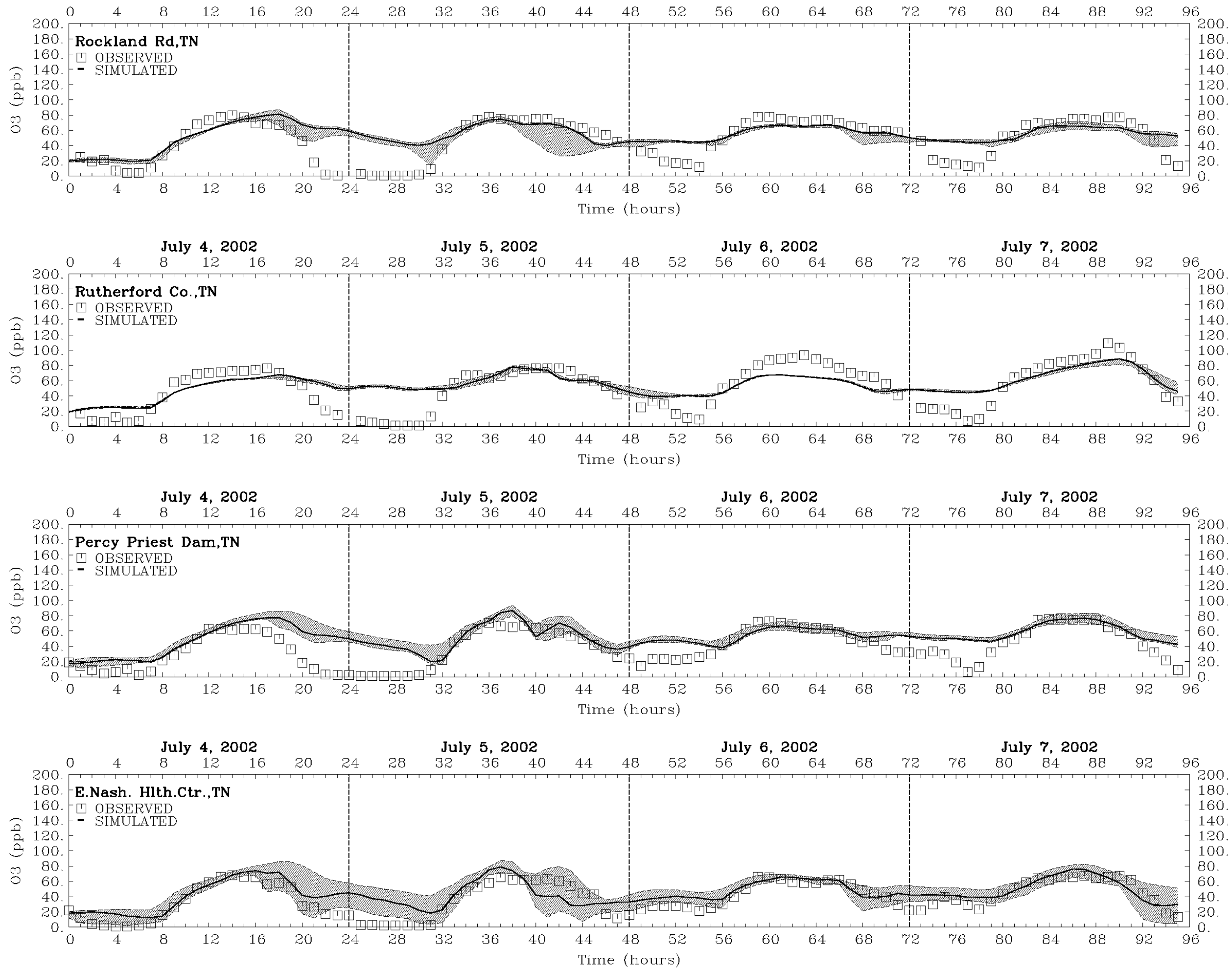


Figure 6-11d.
2001 Episode Time Series: Nashville EAC Area *(continued)*,
July 4-7, 2002

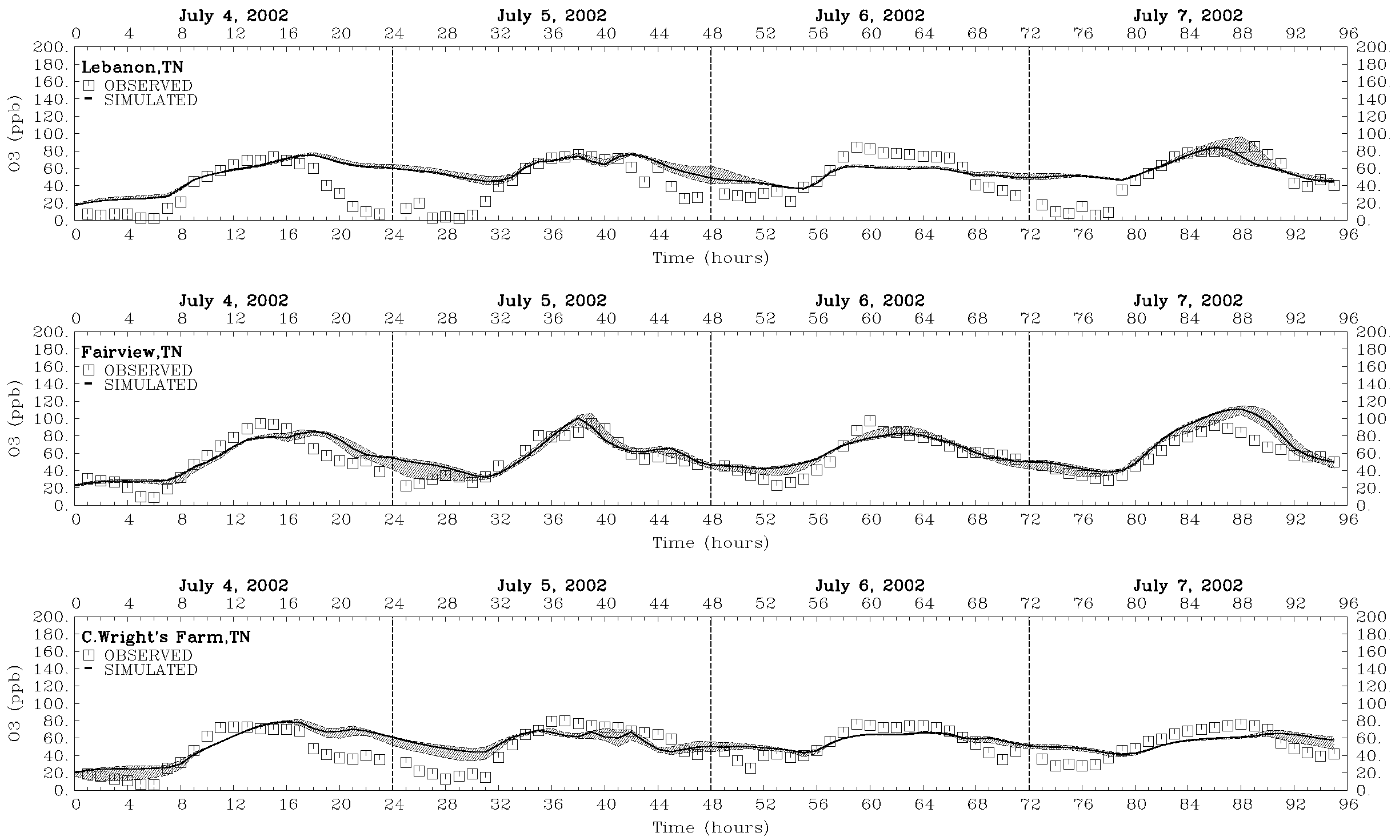


Figure 6-11e.
2001 Episode Time Series: Nashville EAC Area,
July 7-10, 2002

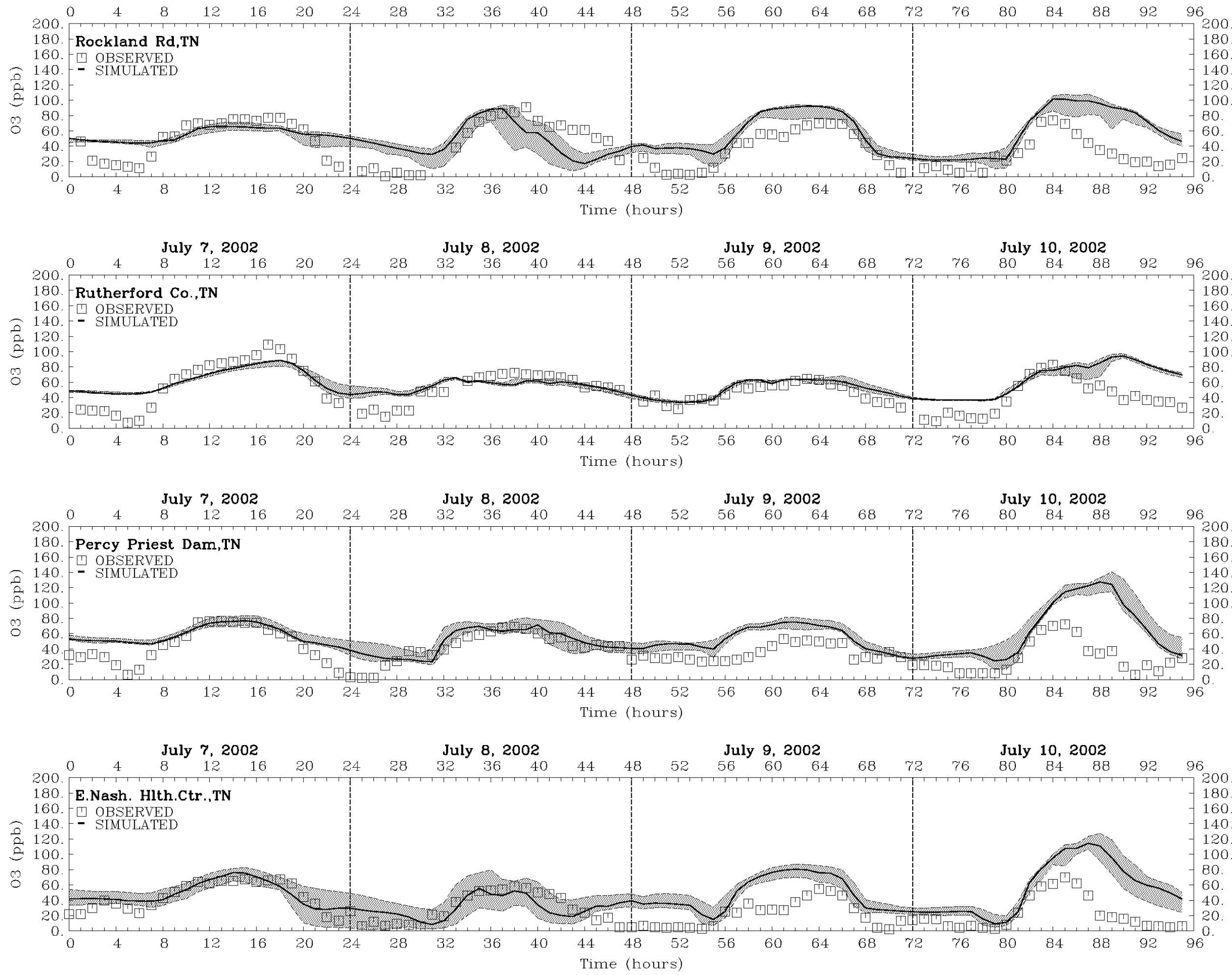


Figure 6-11f.
2001 Episode Time Series: Nashville EAC Area *(continued)*,
July 7-10, 2002

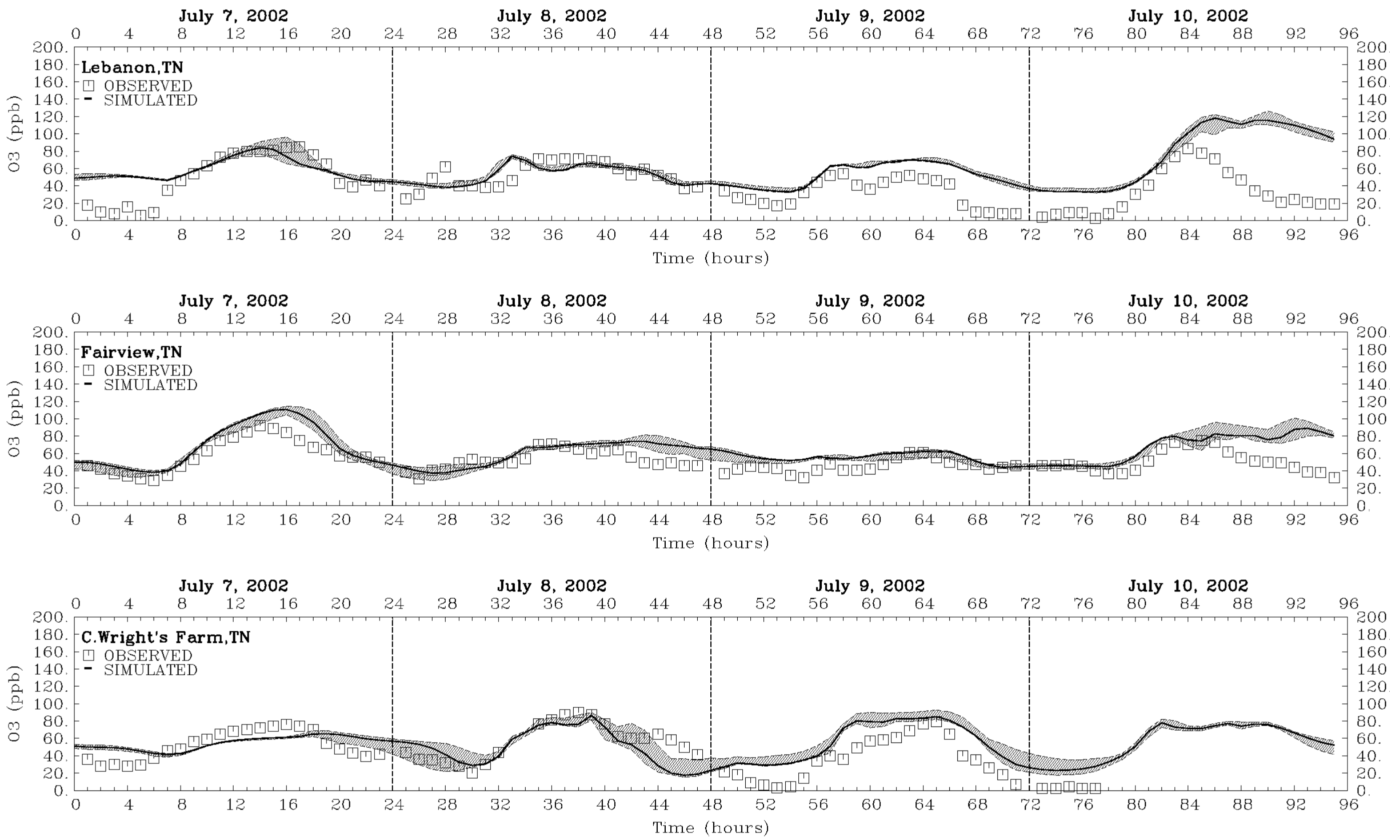


Figure 6-11g.
2001 Episode Time Series: Knoxville EAC Area,
July 4-7, 2002

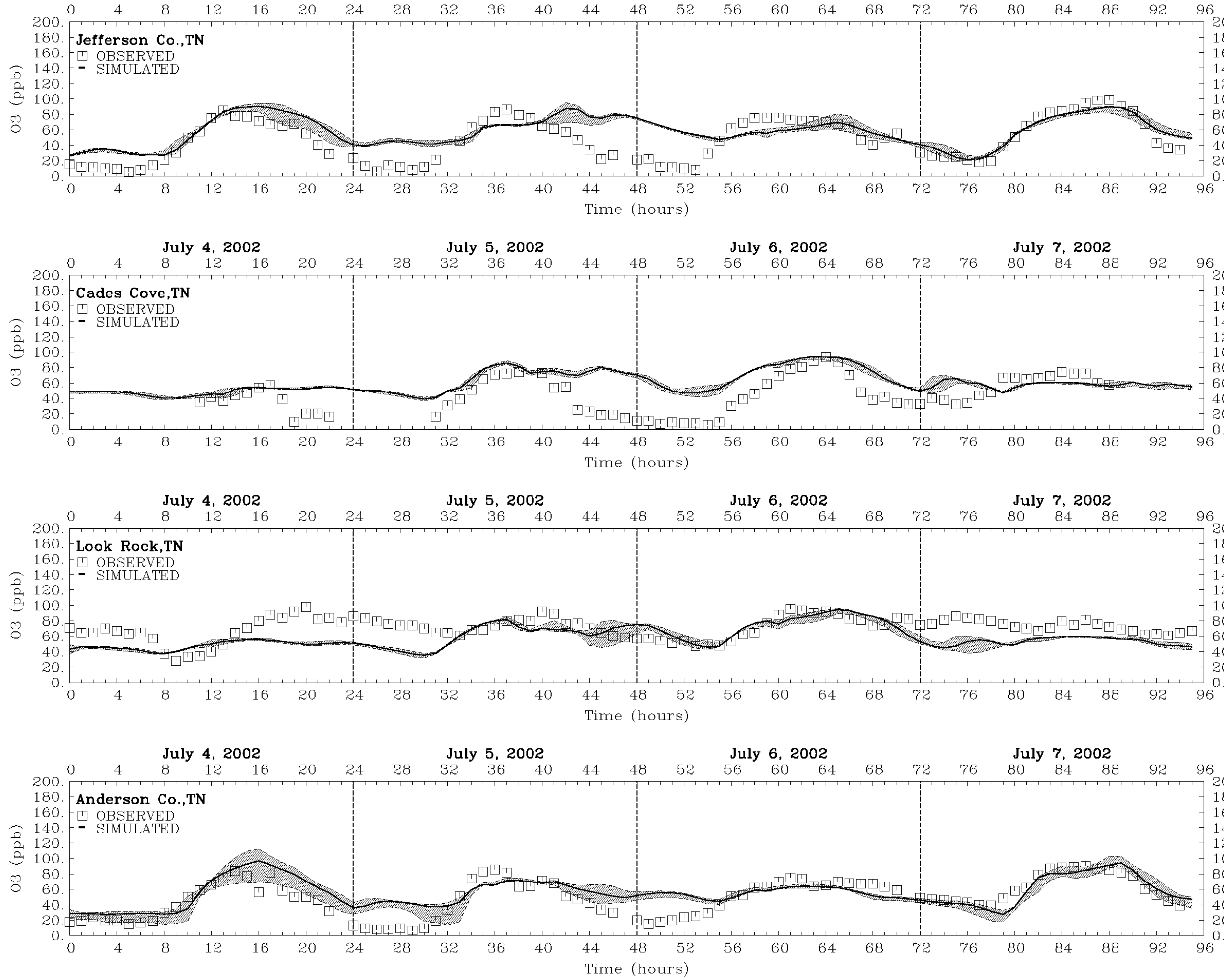


Figure 6-11h.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,
July 4-7, 2002

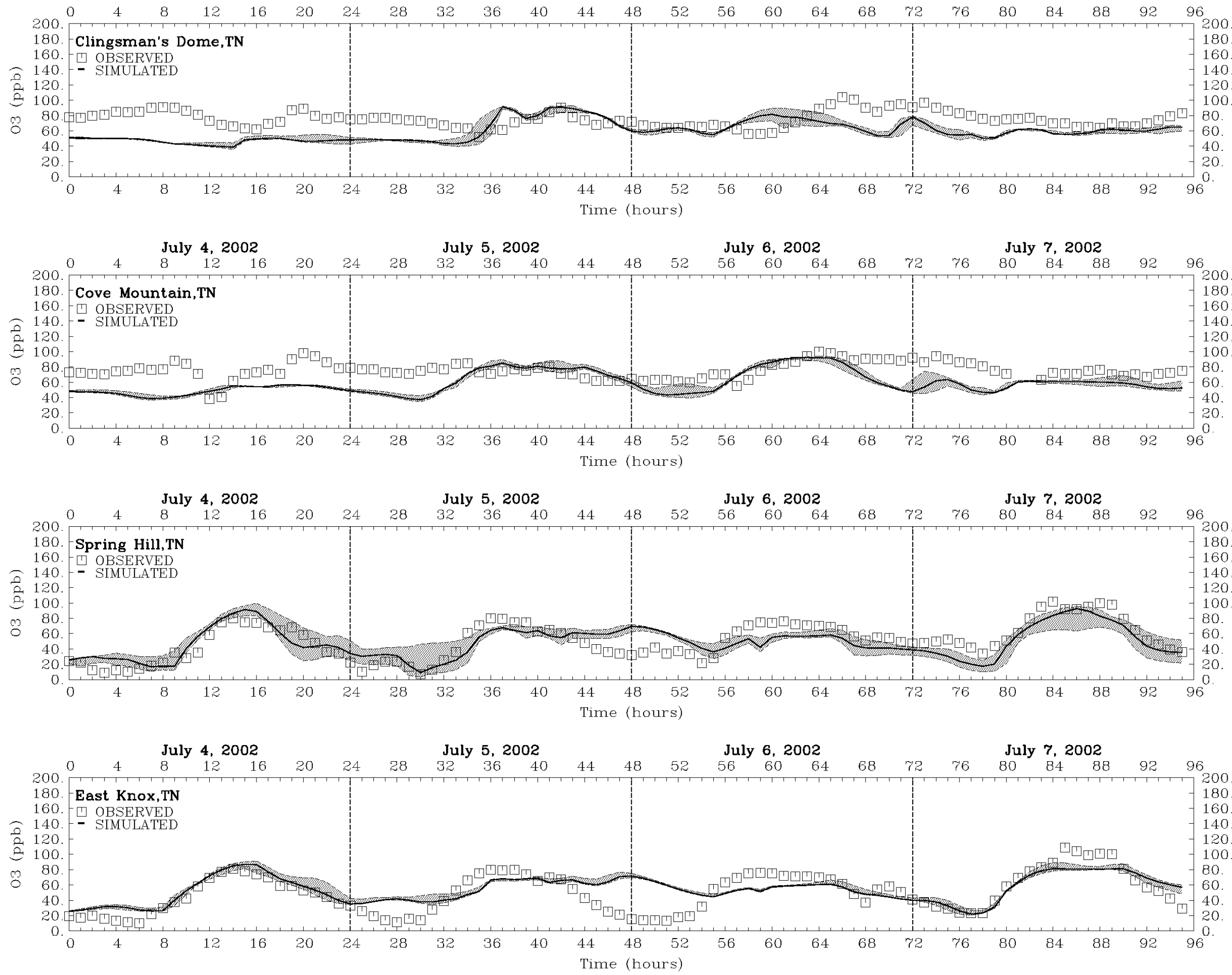


Figure 6-11i.
2001 Episode Time Series: Knoxville EAC Area,
July 7-10, 2002

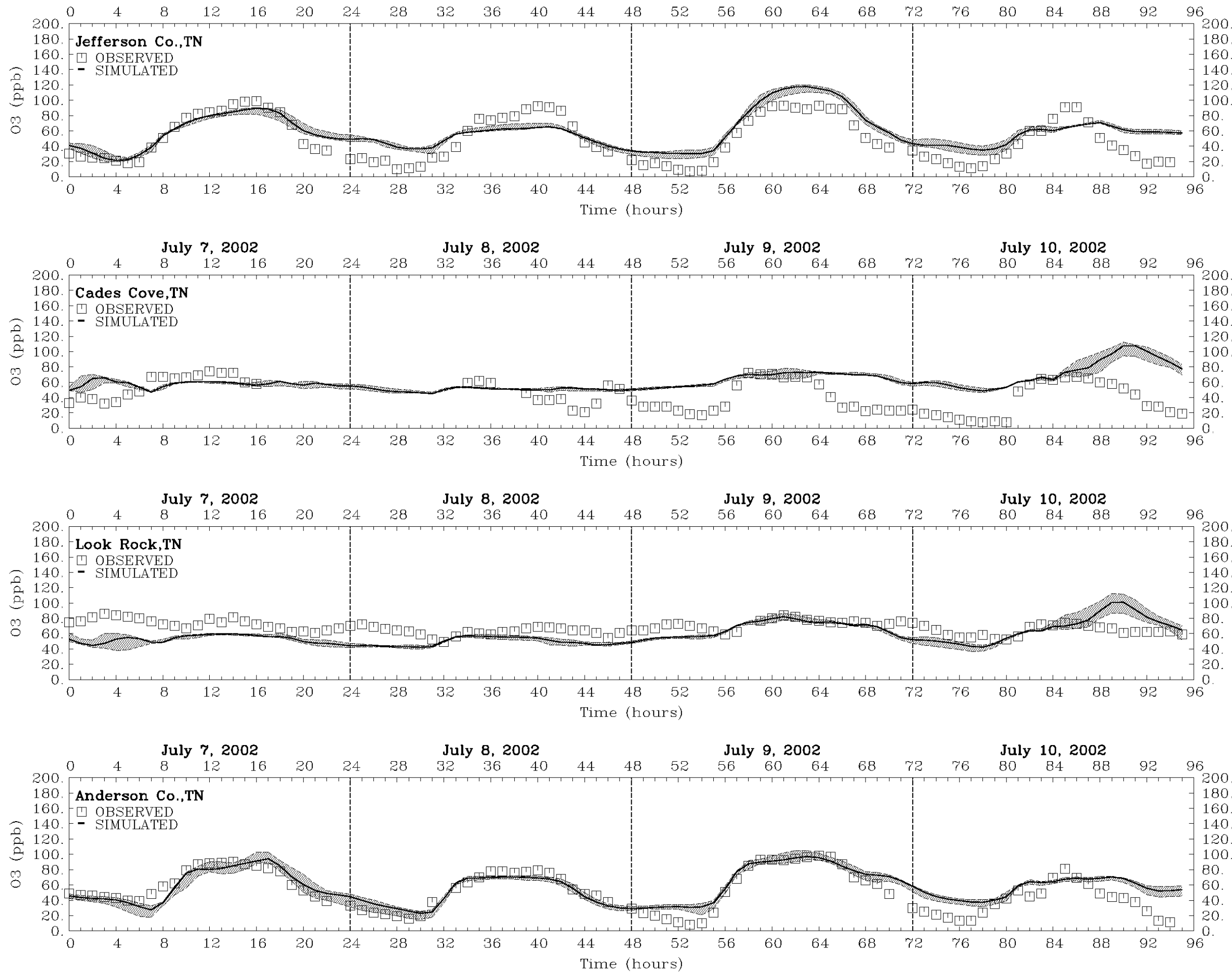


Figure 6-11j.
2001 Episode Time Series: Knoxville EAC Area ***(continued)*****,**
July 7-10, 2002

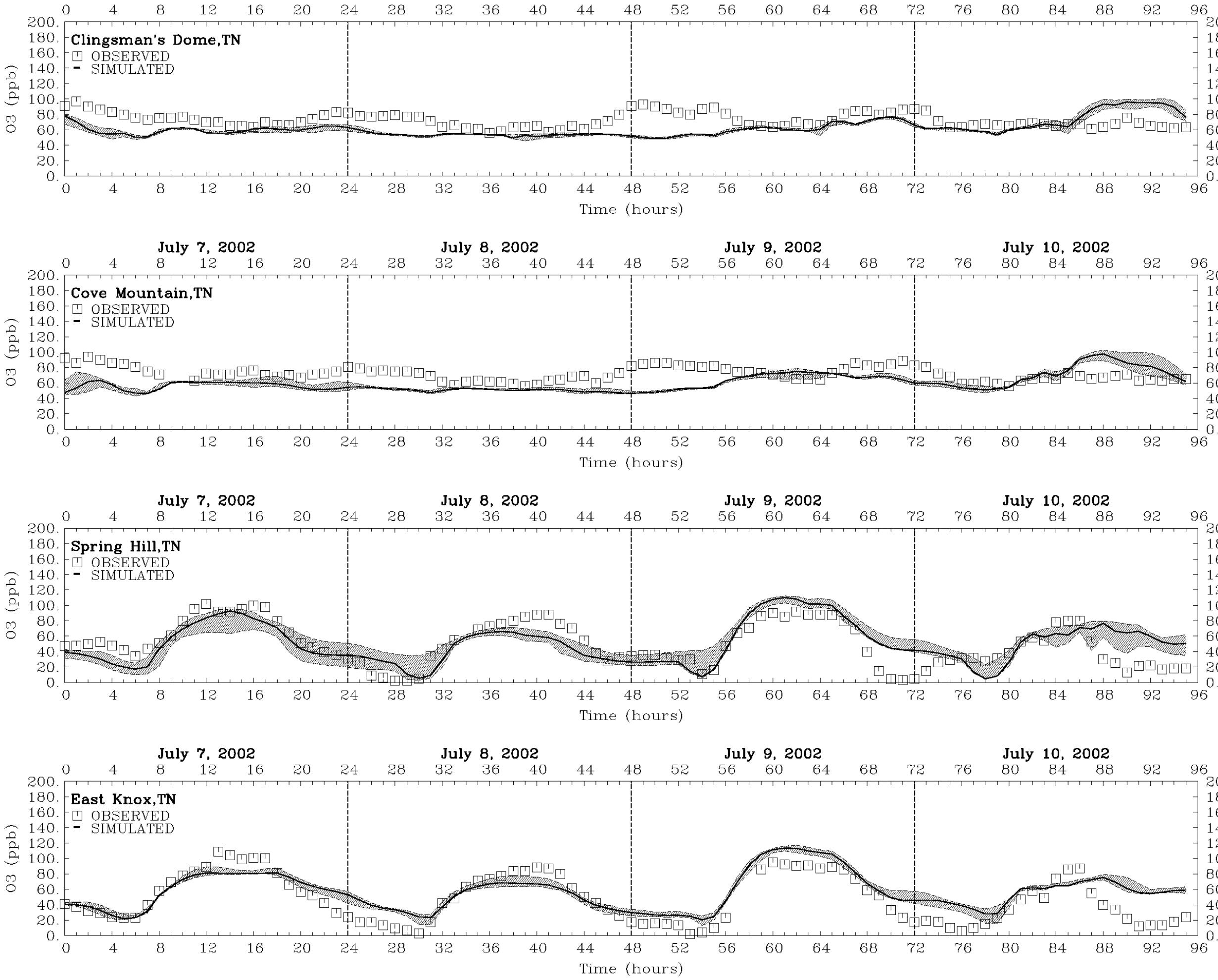


Figure 6-11k.
2001 Episode Time Series: Chattanooga EAC Area,
July 4-7, 2002

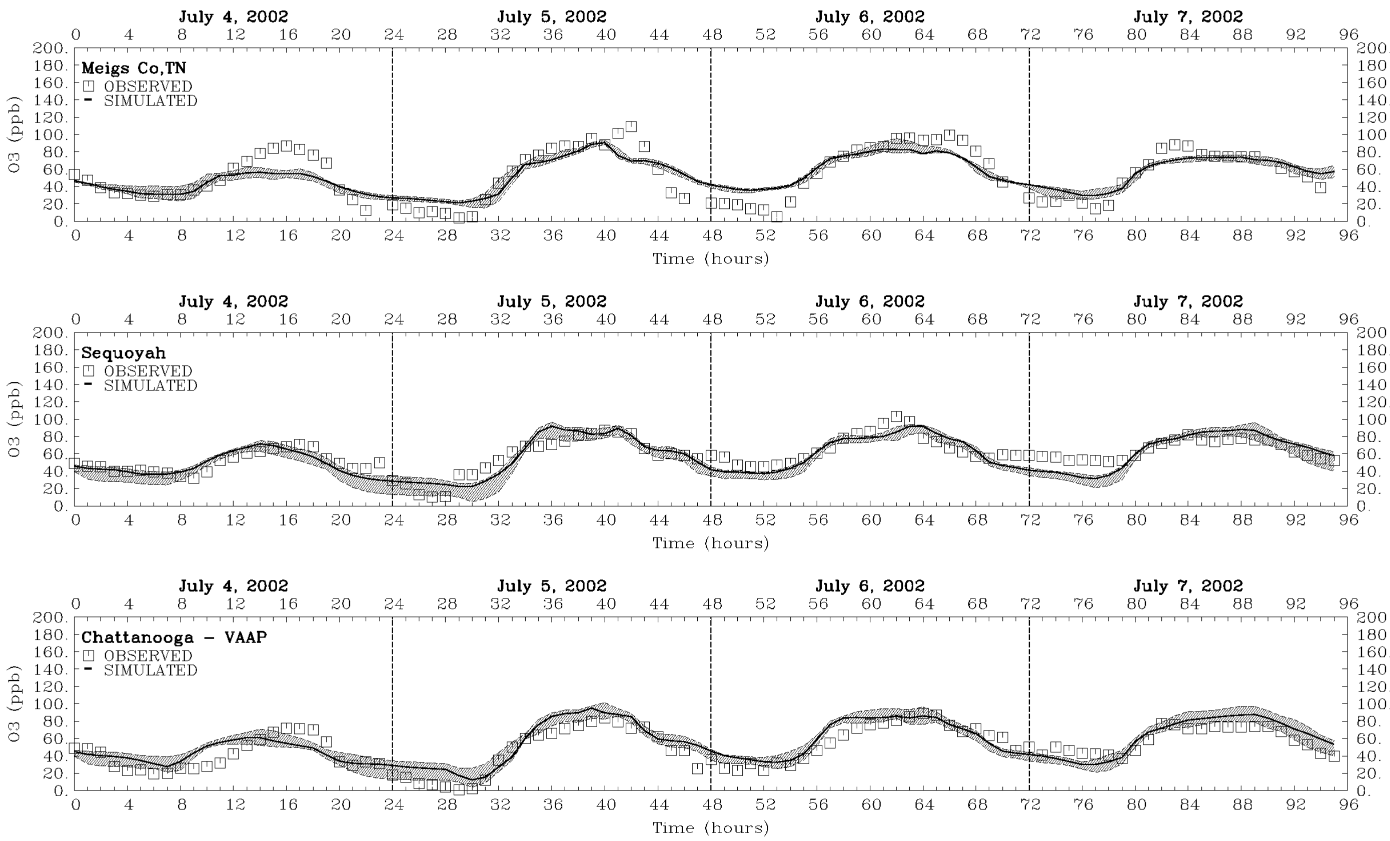


Figure 6-11l.
2001 Episode Time Series: Chattanooga EAC Area,
July 7-10, 2002

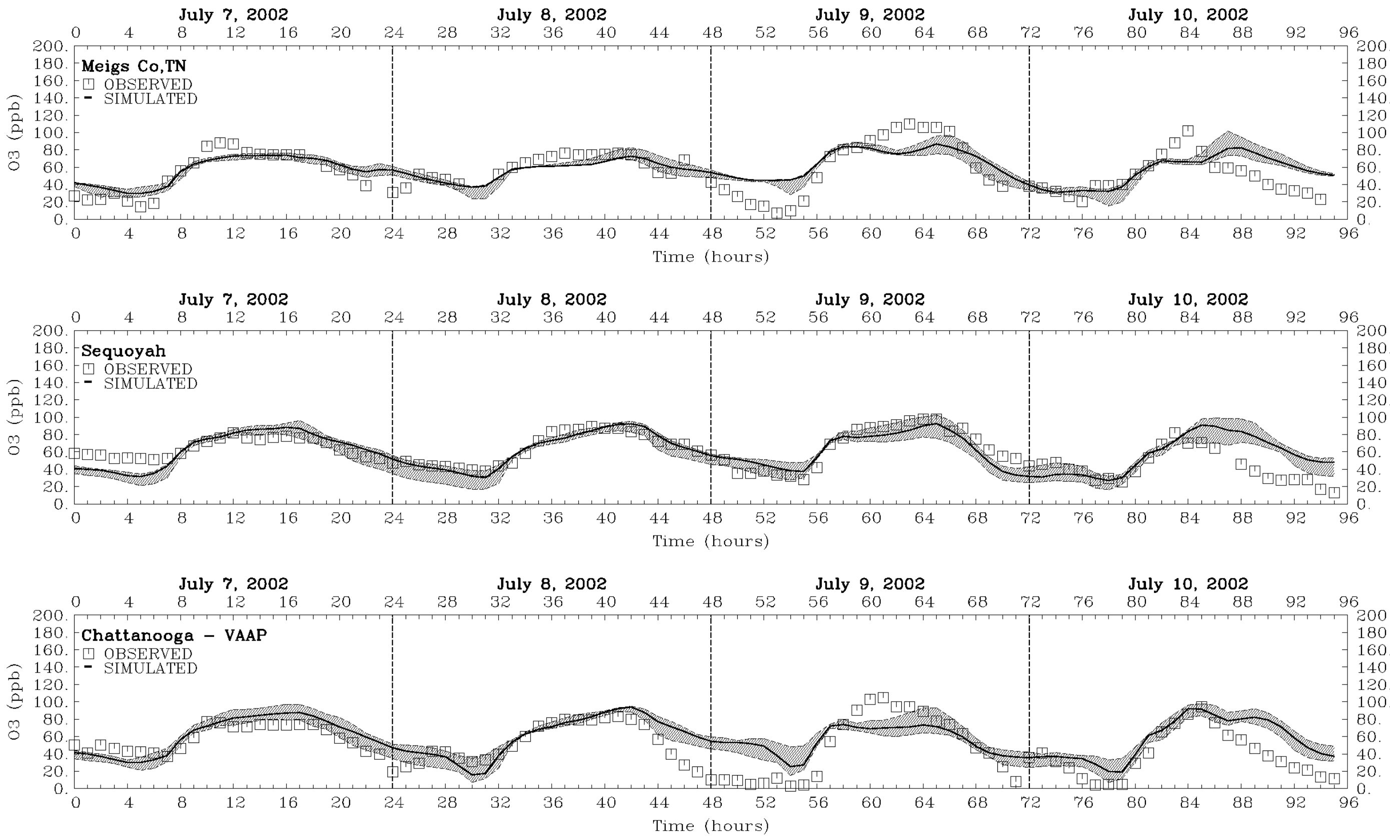


Figure 6-11m.
2001 Episode Time Series: Tri-Cities EAC Area,
July 4-7, 2002

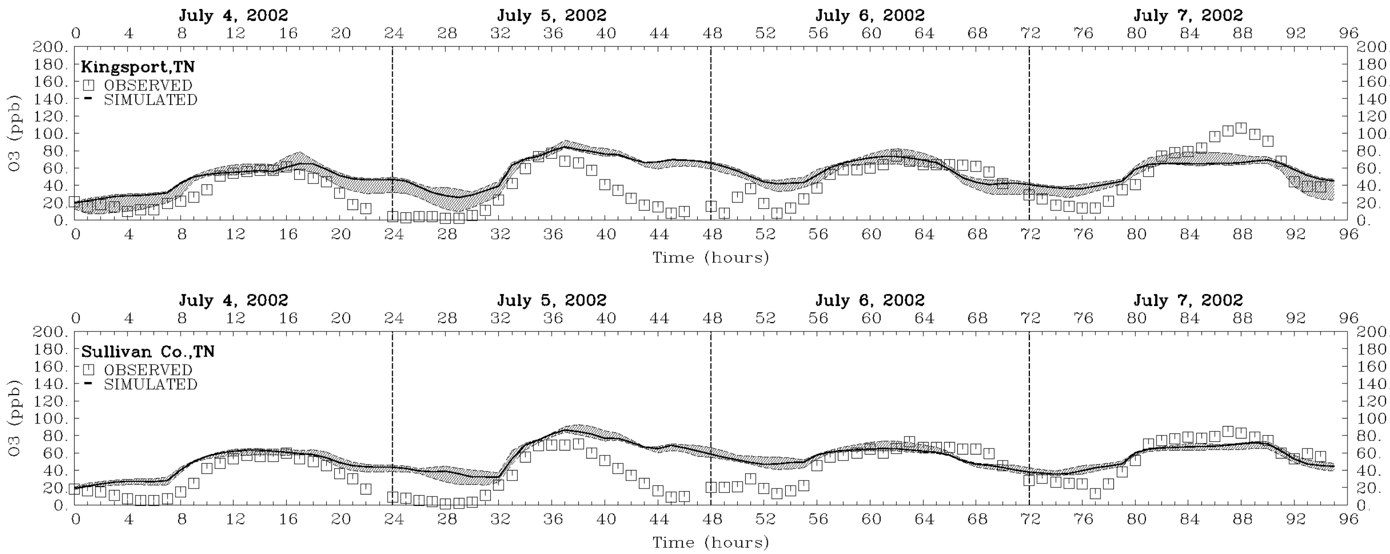


Figure 6-11n.
2001 Episode Time Series: Tri-Cities EAC Area,
July 7-10, 2002

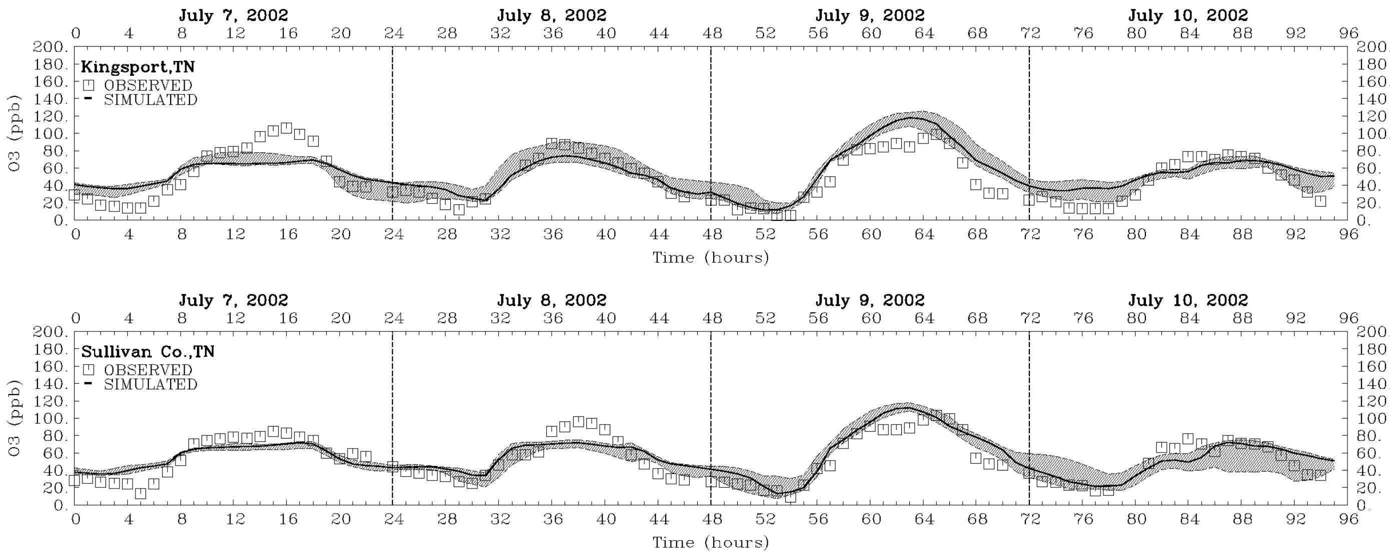
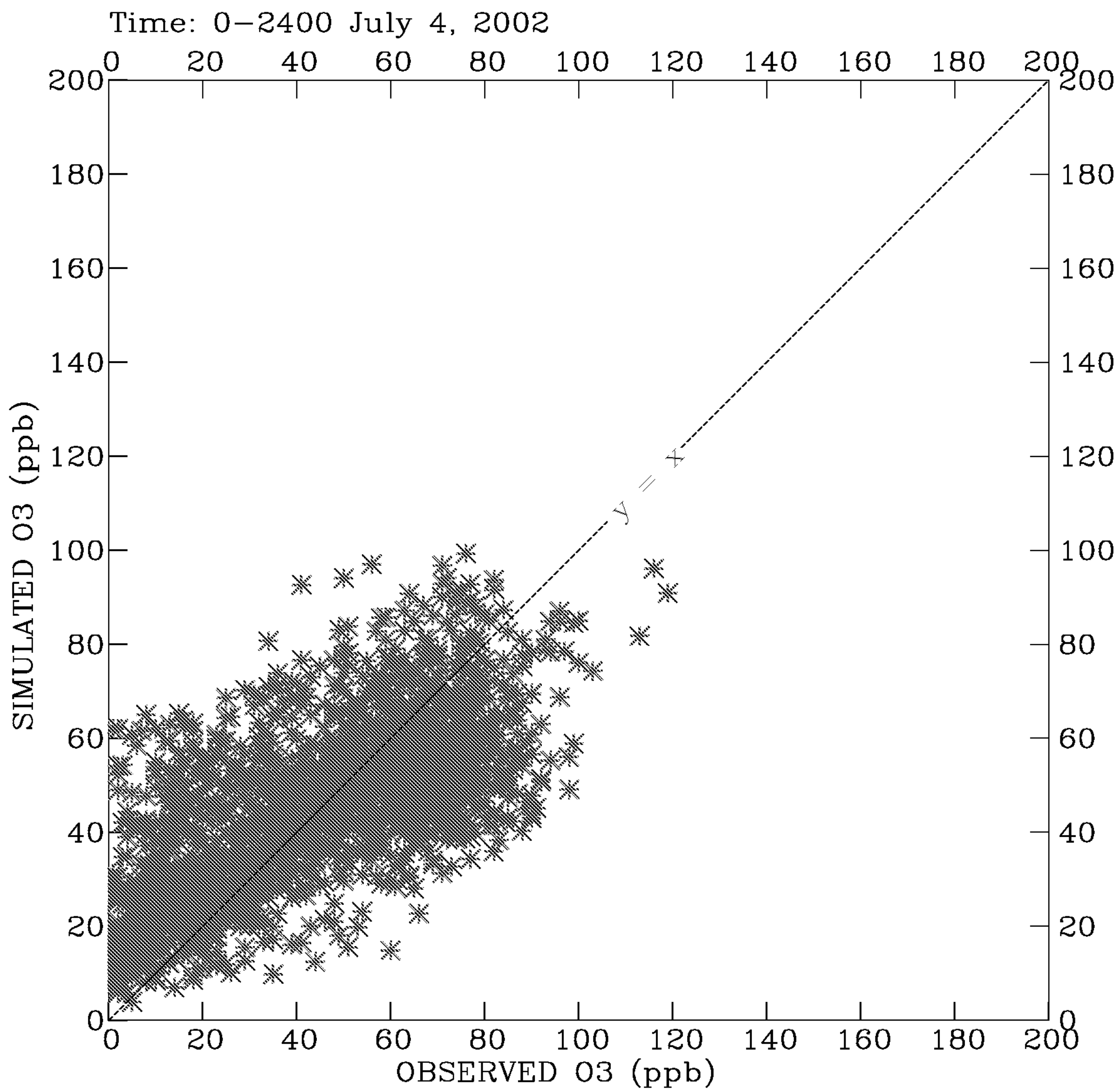
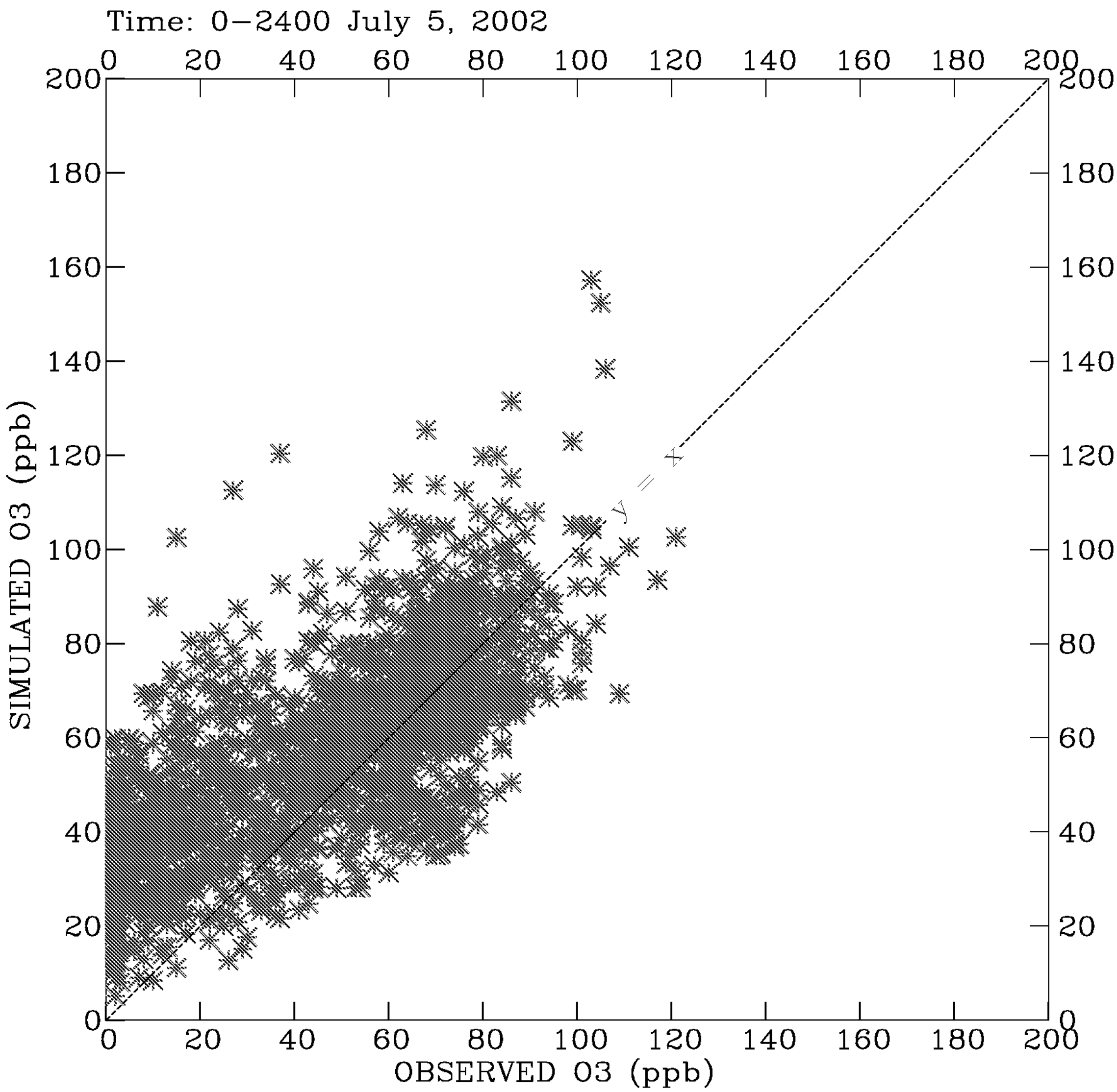


Figure 6-12a.
Scatter Plot: July 4, 2002



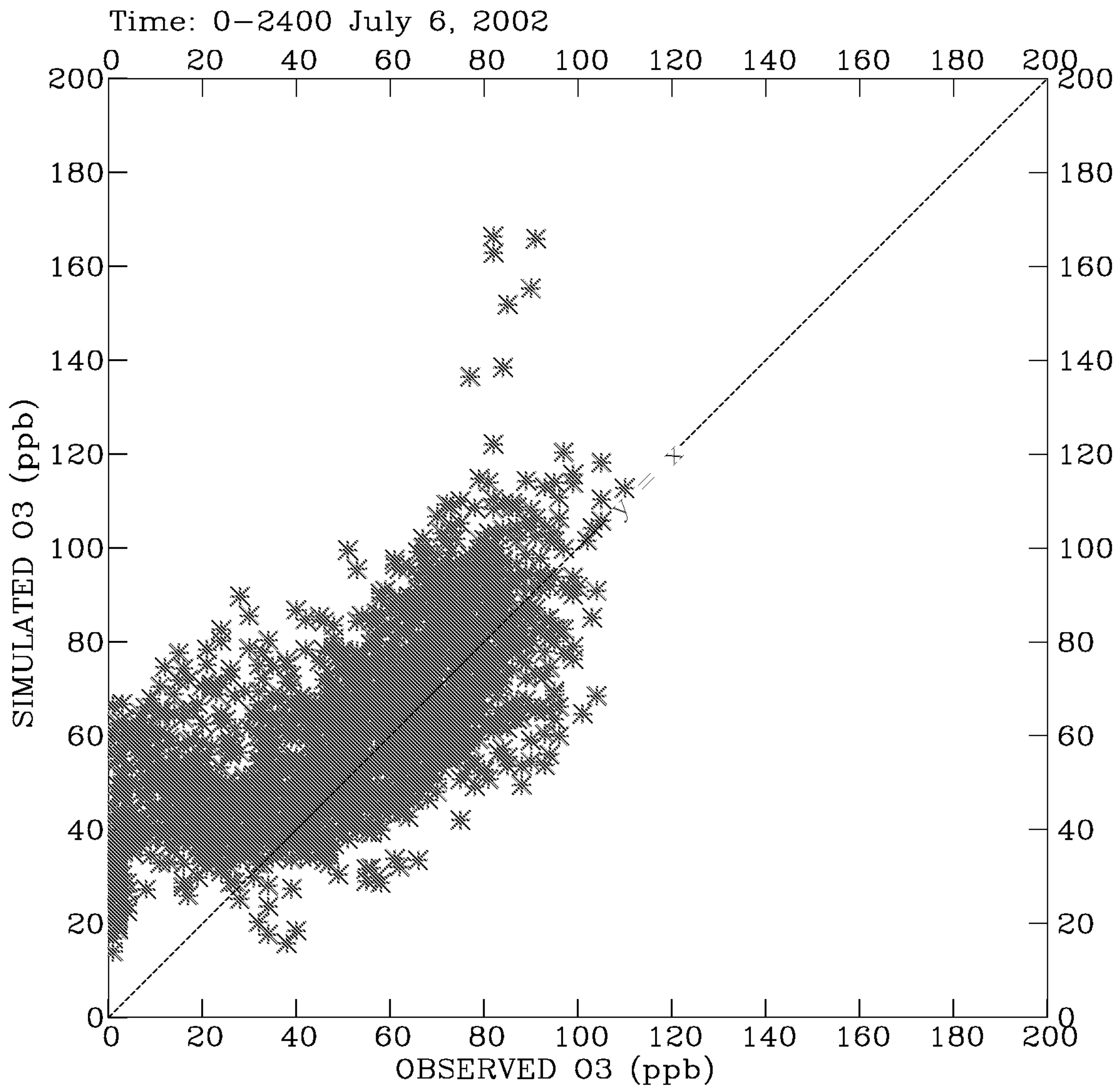
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12b.
Scatter Plot: July 5, 2002



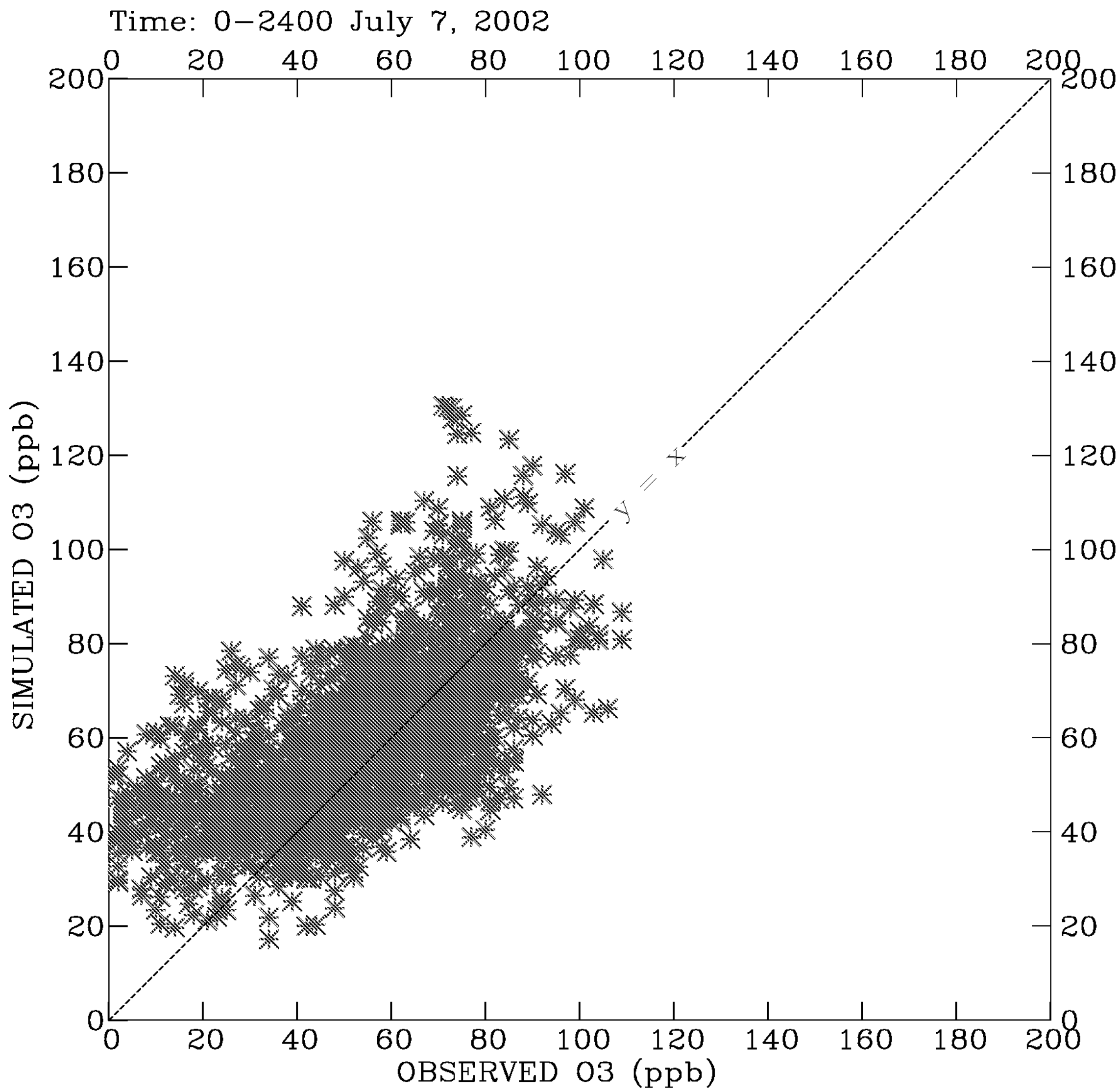
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12c.
Scatter Plot: July 6, 2002



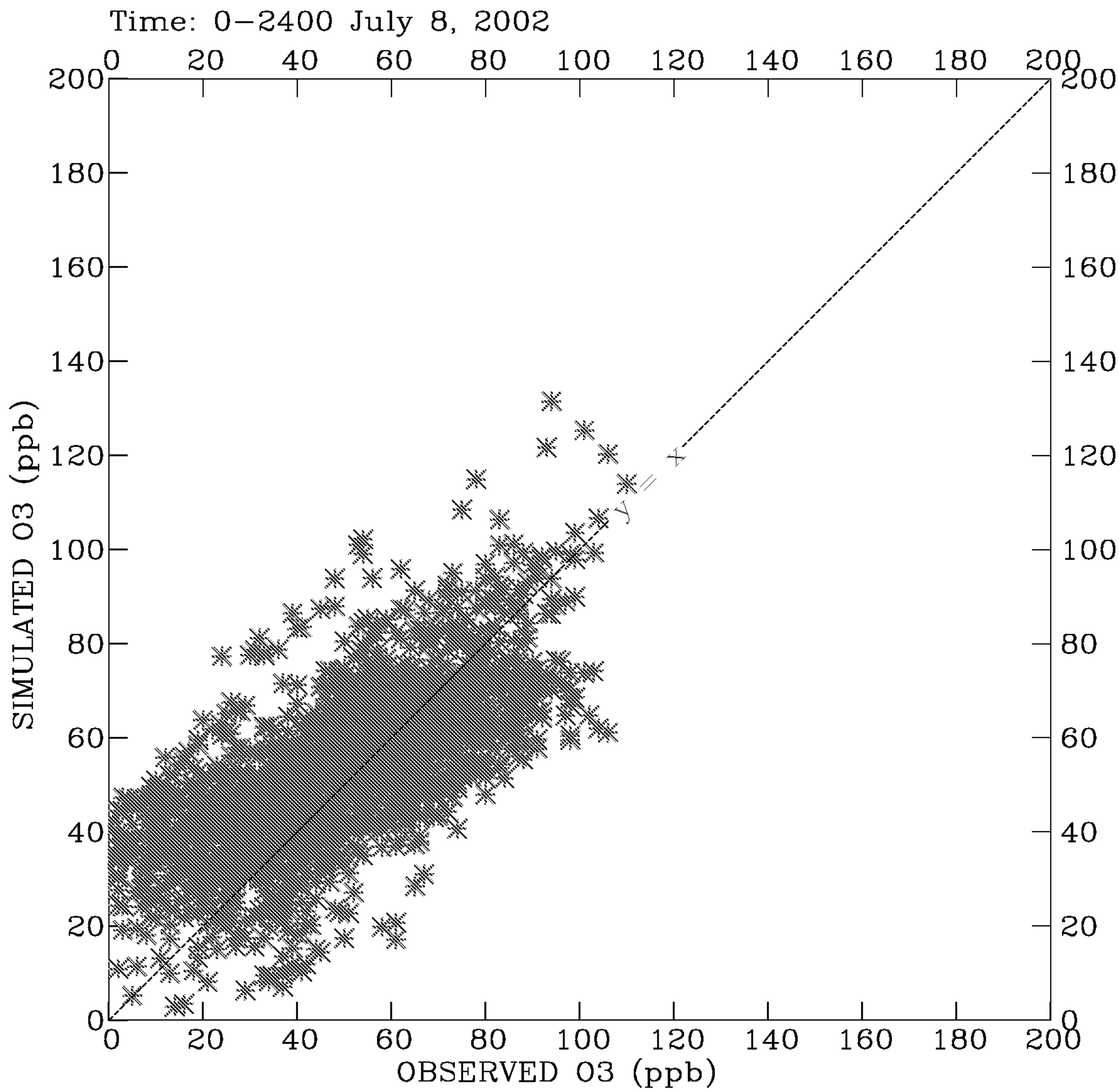
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12d.
Scatter Plot: July 7, 2002



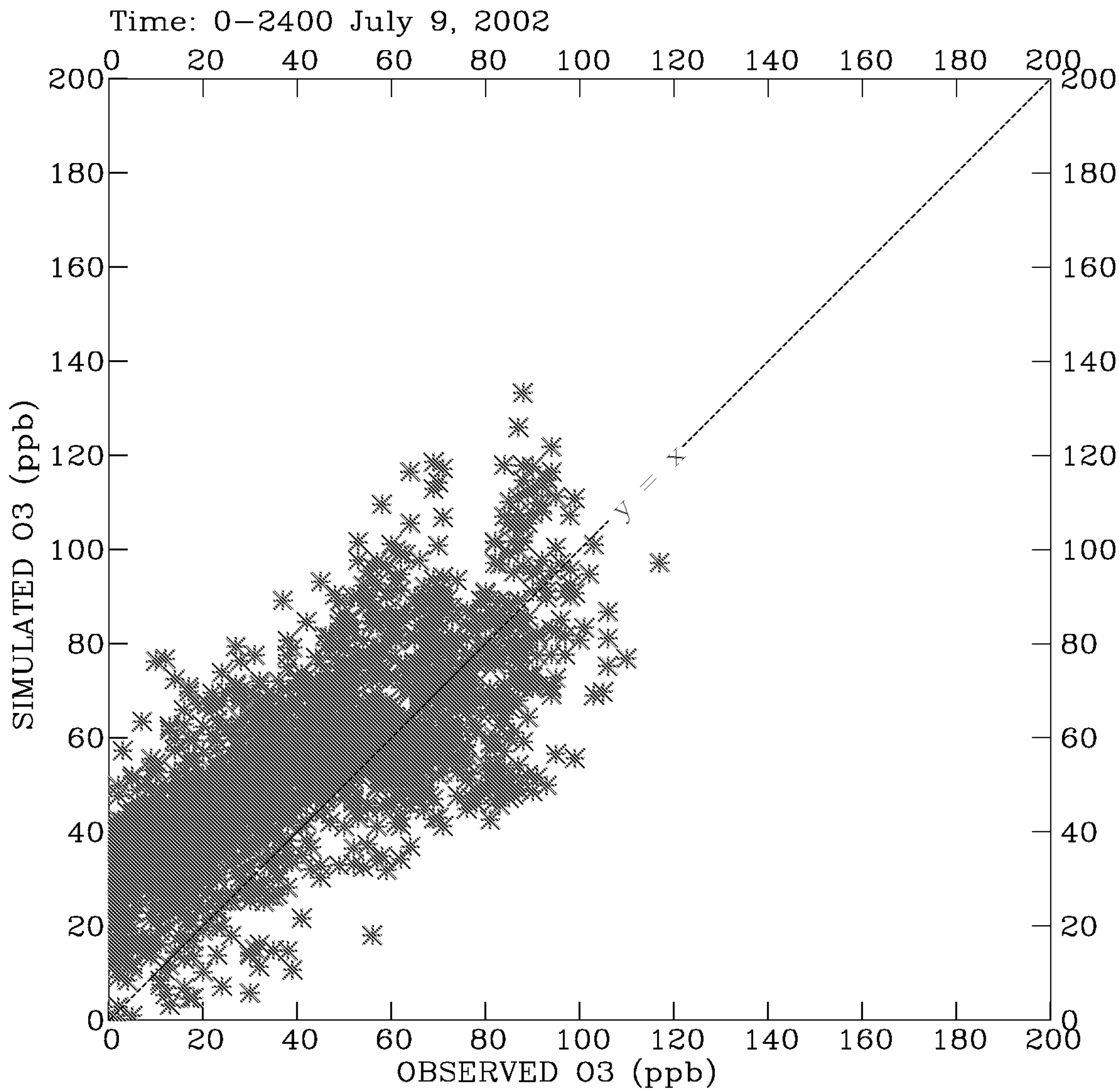
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12e.
Scatter Plot: July 8, 2002



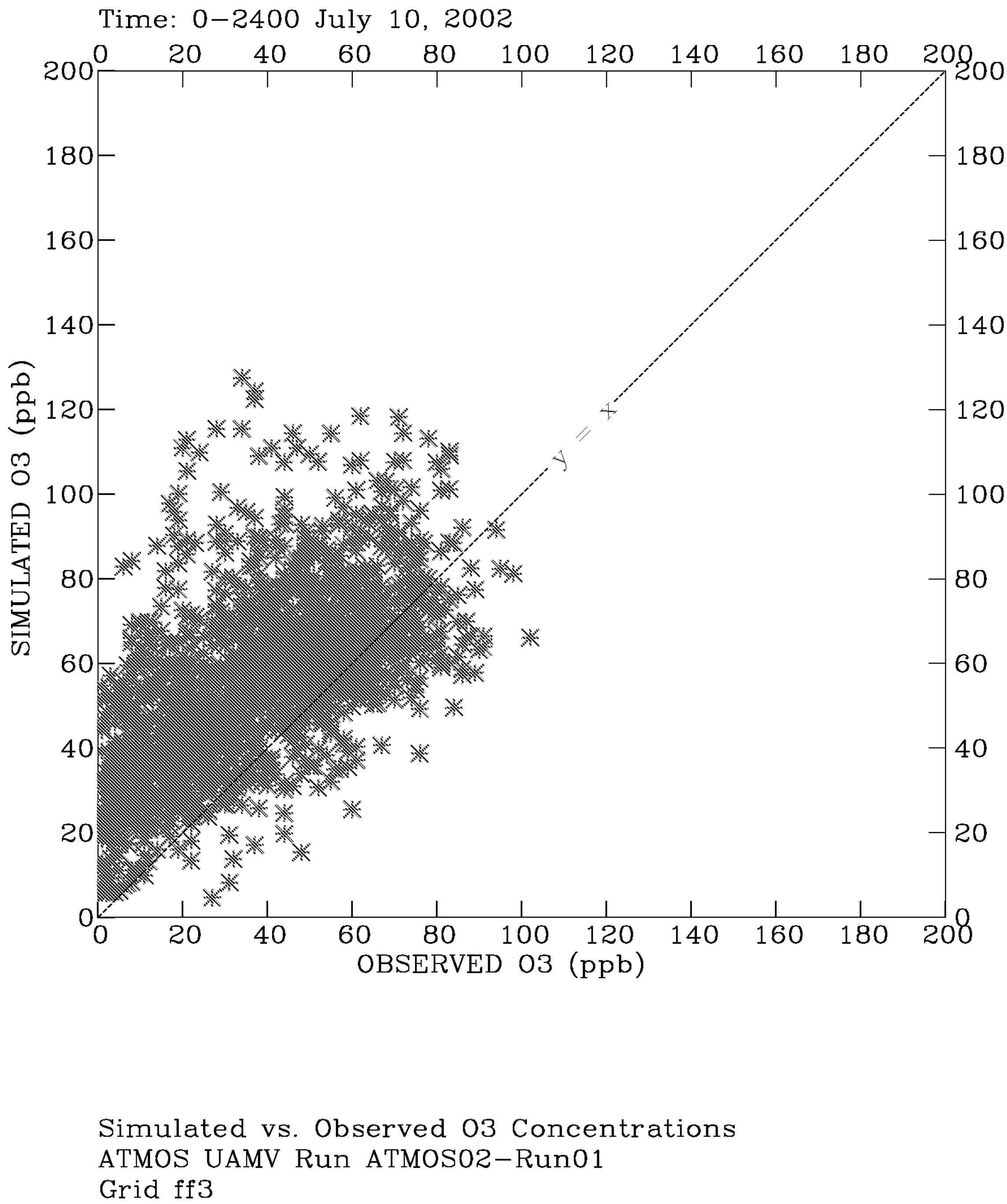
Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12f.
Scatter Plot: July 9, 2002



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12g.
Scatter Plot: July 10, 2002



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7. Future-Year Modeling Application

The ATMOS EAC future-year modeling analysis included the development of future-year emission inventories (2007 and 2012), and the application of the UAM-V modeling system for a "current" year of 2001, two future years (2007 and 2012), as well as a number of EAC control measure sensitivity simulations. In addition to the 2007 baseline scenario, emissions for 2012 were developed, as required by EPA, to assess the effects of growth and as an evaluation of expected maintenance of the standard five years beyond 2007.

The UAM-V modeling system was run for the two ATMOS episodes and a third episode provided by the Arkansas DEQ using current-year (2001) emissions. This allowed the combination of results in applying the EPA modeled attainment test procedures, despite the different base years. Many of the comparisons presented in this section also rely on the 2001 current-year results as the basis for comparison. Following the preparation of the 2007 baseline emission inventory, future-year baseline simulations for 2007 were run and the results were compared with the base- and current-year simulation results. Following completion of the 2007 baseline scenario, two types of future-year simulations were conducted:

- The UAM-V Ozone and Precursor Tagging Methodology (OPTM) was applied to the 2007 baseline simulation to assess the contribution to ozone concentrations from NO_x and VOC emissions from various source categories or source areas within the ATMOS modeling domain.
- Control-strategy simulations for 2007 were used to examine and quantify the effects of specific emissions changes (for selected sources and source categories) for selected EAC measures.

Following a discussion of the future-year emission inventory preparation, the future-year modeling results are presented and discussed in this section.

For ease of reading, all figures follow the text in this section.

Overview of ADVISOR

Before discussing the future year emission inventory preparation and presenting the future-year simulation results, we first introduce the ACCESS™ Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR) analysis tool that was used in the ATMOS EAC modeling analysis to examine and display the emissions and modeling results. The ATMOS ADVISOR is included as electronic attachment to this report.

ATMOS ADVISOR

The ATMOS ADVISOR is an interactive database tool that contains information for review, comparison, and assessment of the UAM-V base and sensitivity simulations. The database contains emissions and simulated ozone concentrations (as represented by several different metrics) for all of the UAM-V modeling grids and selected geographical subregions and monitoring site locations. The ADVISOR database also supports application of draft EPA ozone attainment demonstration procedures (including the calculation of site-specific relative reduction factors and estimated design values) that were developed by EPA for use in 8-hour ozone attainment demonstration modeling.

The ATMOS EAC ADVISOR metrics include:

- Maximum 1-hour ozone concentration (ppb).
- Maximum 8-hour ozone concentration (ppb).
- Number of grid cell·hours with maximum 1-hour ozone concentrations ≥ 125 ppb.
- Number of grid cells with maximum 8-hour ozone concentrations ≥ 85 ppb.
- Total ozone exposure (ppb·grid cell·hour).
- 1-hour ozone exceedance exposure (ppb·grid cell·hour) for 1-hour ozone concentrations ≥ 125 ppb.
- 8-hour ozone exceedance exposure (ppb·grid cell) for 8-hour ozone concentrations ≥ 85 ppb.
- Population[4] exposure (ppb·person hours) to 1-hour ozone concentrations ≥ 125 ppb.
- Population exposure (ppb·person) to 8-hour ozone concentration ≥ 85 ppb.
- Total and component emissions (NO_x, VOC).

Options for displaying the metrics include:

- Value.
- Difference (relative to a selected base simulation such as the future-year baseline).
- Percentage difference.
- Effectiveness (change in ozone metric relative to the change in emissions[5], again relative to a selected base simulation).
- Relative reduction factor.
- Estimated design value.

- Observed ozone concentrations are also displayed.

Geographies consisting of grids, subregions, and monitoring sites include:

- Grid 1: Outer 36 km X 36 km grid.
- Grid 2: Intermediate 12 km X 12 km grid.
- Grid 3: Inner 4 km x 4 km inner grid.
- Sumner, Davidson, Wilson, & Rutherford Counties, TN (Nashville).
- Knox, Anderson, Jefferson, Sevier, and Blount Counties, TN (Knoxville).
- Shelby, DeSoto, and Crittenden Counties (Memphis).
- Shelby County, TN.

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4 Population estimates are based on 2000 U.S. Census data.

5 The change in emissions can be calculated for a different geographical area than the change in ozone metric.

- DeSoto County, MS.
- Crittenden County, AR.
- Lee County, MS (Tupelo).
- Pulaski County, AR (Little Rock).
- Hamilton County, TN; Walker and Catoosa Counties, GA (Chattanooga).
- Nashville EAC Area: (Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson counties).
- Knoxville EAC Area: (Anderson, Blount, Know, Loudon, Sevier, Union, and Jefferson counties).
- Chattanooga EAC Area: (Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa counties, (Georgia)).
- Memphis EAC Area: Shelby, Tipton, and Fayette counties (Tennessee); Crittenden County, (Arkansas); De Soto County, (Mississippi).
- Tri-Cities EAC Area: (Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington counties).
- Haywood County.
- Lawrence County.
- Putnam County.

In addition to these specific areas, the ozone monitoring sites in the ATMOS Grid 3 are also included in the ADVISOR database.

An estimate of the modeling system noise, as calculated for certain of the metrics, is also included as a display option in the ADVISOR database. This feature is intended to provide perspective on the meaningfulness of the simulated ozone reductions.

In this report, the simulation results are presented and compared using three primary metrics or indicators:

- Maximum 8-hour ozone concentration is the simulated maximum 8-hour average ozone concentration for a given "geography" (grid, subregion, or monitoring site) and time period. The units are ppb.
- 8-hour ozone exceedance exposure is a measure of the "excess" simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied.
- The estimated design value (EDV) is an estimate of the 8-hour ozone design value for a selected monitoring site and future-year scenario. It is calculated as the current design value multiplied by a relative reduction factor (RRF), where the RRF is the ratio of the future-year-scenario to base-year 8-hour ozone concentration in the vicinity of the monitoring site. This metric will primarily be used to discuss the results from the application of the draft 8-hour ozone attainment demonstration procedures in the next section of this report. The units are ppb.

Additional metrics are used to assess and compare the modeling results, as suggested in EPA's 8-hour modeling guidance document. The metrics below are intended for use in a relative sense, comparing the base case (or current year) simulation with the future year simulation:

- The number of grid cells for which the daily maximum 8-hour concentration is greater than 84 ppb.
- The number of hours where the 1-hour concentration is greater than 84 ppb in each grid cell.
- The 1-hour exceedance exposure for concentrations greater than 84 ppb. The units are ppb, with grid-cell and day implied.

Future-Year Emission Inventory Preparation

This section discusses the methodologies followed in preparing the future-year baseline emission inventory for 2007.

Emission Inventory Growth Factors

The projection of the ATMOS EAC base year emission inventory to the future years required the use of economic growth factors. These are applied to the various industrial sectors and source categories to reflect expected future growth (or decline) in industrial activity and resulting emissions. There are five sets of factors available for use in projecting emission inventories for air quality modeling. The Bureau of Economic Analysis (BEA) provides three such sets, while another two sets are available in EPA's Economic Growth Analysis System (EGAS). For ozone SIP modeling exercises, EPA guidance does not state a preference regarding which set to use, but does recommend that local growth information be considered in the selection and use of such factors. The BEA projection series provides state-level personal earnings, employment, and gross state product (GSP - value added) data for selected years through the year 2045, and the projection factors are available at 2-digit SIC code level for point sources and 4-digit ASC code level for area sources. The latest set of growth factors provided by BEA was issued in 1995—BEA no longer publishes growth factors. The EGAS system includes both BEA factors and two other sets of growth factors that purportedly provide more detailed information—geographically and by source category. The EGAS provides the county-level growth factors for area sources at the 10-digit ASC code level, and growth factors for point sources at the 2-digit SIC code level with associated fuel type or 8-digit SCC code. The two sets of factors provided by EGAS are from the Bureau of Labor Statistics (BLS) and from Wharton Econometric Forecasting Associates (WEFA). Although the EGAS system purports to provide growth factors by county, for the State of Tennessee and all other surrounding states, all of the factors contained in the latest version of EGAS are the same for all counties within each state—there are no county-to-county differences.

For the ATMOS EAC modeling analysis, the future-year emission inventories for 2007 and 2012 were developed using economic growth factors provided by the BEA. Specifically, the state-specific GSP factors were used for all states (except Louisiana, where employment factors were used) within the modeling domain. The selection of the BEA factors was not based on any assessment of the quality or accuracy of BEA vs. EGAS. EPA guidance does recommend that value added projections be used and BEA's GSP factors are a measure of value added and a more complete measure of growth than BEA's earnings factors, which are only one component of GSP. The BEA GSP factors have been used recently by EPA in ozone and particulate matter modeling conducted to support national rulemaking for the Tier 2 engine and fuel sulfur standards, the nonroad diesel engine rulemaking, the Clear Skies Initiative (CSI), and most recently, in the Interstate Air Quality Rule (IAQR) modeling analysis (EPA, 2004).

Area-Source and Non-road Emissions

Area Source Projection

The future-year growth estimates for area sources were based on Bureau of Economic Analysis (BEA) projections of Gross State Product (GSP) for all states except for the State of Louisiana, which was based on the Employment (BEA, 1995). The BEA projections were applied at the 4-digit ASC level for area sources, and represent growth between the current year (2001) and 2007. The BEA growth factors are presented in Appendix B (Tables B-1 through B-6 for all states excluding the State of Louisiana), and BEA employment growth factors for the State of Louisiana are presented in Table B-7.

Area Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from the U.S. Department of Energy (DOE) publication *Annual Entergy Outlook 1999* (DOE, 1998), were applied to the baseline emissions to account for expected increases in fuel and process efficiency in 2007. The adjustment factors are presented in Table B-8.

VOC controls were applied to area sources using information provided by EPA. The controls include federal initiatives, such as VOC content limits for consumer solvents, Title III Maximum Achievable Control Technology (MACT) assumptions, and Title I Reasonably Available Control Technology (RACT) assumptions that were not applied in the base year inventory. These controls are presented in Table B-9.

Table B-10 shows the VOC and CO controls applied for residential wood combustion, and Table B-11 lists the control efficiencies applied to account for VOC reductions associated with onboard vapor recovery systems and Stage II controls at gasoline service stations (percentage reductions for counties required to have Stage II controls, and counties that do not have Stage II controls).

All emissions due to open burning were eliminated for the 45 counties in Northern Georgia (Georgia Department of Natural Resources Environmental Protection Division: Georgia's State Implementation Plan for the Atlanta Ozone Non-attainment Area, July 17, 2001) (GDNR, 2001), and 8 counties in the State of Alabama by a seasonal ban. The 45 counties in Northern Georgia are 13 non-attainment and 32 additional counties (eliminated both prescribed and slash burning for Bartow, Carroll, Hall, Newton, Spalding and Walton counties; and eliminated slash burning for Banks, Barrow, Butts, Chattooga, Clarke, Dawson, Floyd, Gordon, Haralson, Heard, Jackson, Jasper, Jones, Lamar, Lumpkin, Madison, Meriwether, Monroe, Morgan, Oconee, Pickens, Pike, Polk, Putnam, Troup and Upson counties). The 8 counties in Alabama are Jefferson, Shelby, Baldwin, Lawrence, Madison, Mobile, Montgomery, and Morgan.

Non-road Source Emissions

County-level emission estimates for the majority of non-road mobile source emissions were developed using EPA's draft NONROAD2002a (EPA, 2003) model with the maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state for each month of the episode periods.

Emissions from aircraft, commercial marine and locomotives were projected from the current year (2001) to year 2007 using the BEA GSP growth factors for all states except for the State of Louisiana, which were based on the Employment.

The 2000 non-road mobile source emissions for four counties in State of Arkansas were projected to 2007 using the BEA GSP growth factors.

Emissions for State of Texas

The area and non-road source emissions data for 2007 were obtained from TCEQ, and incorporated into the future-year inventories for all Texas counties included in the modeling domain. The data provided information for preparing the 2007 Mid-Course Review (MCR) Phase I Emissions Inventory including associated growth and controls for NO_x, VOC and CO.

Mobile-Source Emissions

The on-road mobile source emissions were prepared using MOBILE6.2. For the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee and Texas, each state provided estimated 2007 county-level daily VMT forecasts. The 30-year historical average temperatures and humidity data for each month of the episode periods were used in calculating emission factors with MOBILE6.2. For all other states in the domain, the on-road mobile source emissions were prepared using MOBILE6.2 and state-level 2007 VMT information provided by the Federal Highways Administration (FHWA). The state-level VMT data were distributed to the county-level using the 2000 Census population as a surrogate.

The MOBILE6.2 input files were used to generate the emission factors for total organic gases (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6.2 by the county-level VMT for that vehicle class and roadway classification using the EPS 2.5 program MVCALC.

Point-Source Emissions

Point Source Emission Data Source

The 2007 point source emissions were developed based on the following data:

State of Tennessee

- Applied future year growth and controls on the county-specific current year (2001) emissions data.
- Applied 6% growth rate to the base case level emissions for various gas compressor station sources located in the state (June 2001 and August/September 1999 emissions as base case level for larger gas compressors; and 2002 emissions as base case level for smaller gas compressors).

STATE OF MISSISSIPPI

- Applied future year growth and controls on the current emissions data, and included the emissions estimates for the facilities currently under construction that will be operating in 2007.

STATE OF TEXAS

- Incorporated point source emissions estimates included in the TCEQ 2007 MCR Phase I Emissions Inventory.

FACILITY-SPECIFIC DATA

- Incorporated the hourly emissions estimates for 2007 provided by TVA, and assumed that the combustion turbines (CTs) only operate 4 hours on the three intermediate days of each episode: September 6-8 for the August/September 1999 episode; June 18-20 for the June 2001 episode; and July 6-8 for the July 2002 episode.
- Incorporated 2007 emissions estimates provided by Eastman Chemical Company.
- Incorporated 2007 emissions estimates for Williams Refining & Marketing LLC provided by Shelby County, Tennessee.
- Incorporated hourly emissions estimates for 2007 September and July episode periods provided by Southern Company for the West Florida Ozone Study (WFOS) modeling analysis (SAI, 2004) using day of week matches.
- Kept the emissions for the Entergy facilities (located in States of Arkansas, Louisiana and Mississippi) at the base case level.

OTHER STATES

- Applied future year growth and controls on the final 1999 NEI version 2 data.

Point Source Growth

The future year growth for the point sources was based on the BEA projections. The BEA projections were applied at the 2-digit SIC level for point sources, and represent growth between the current year and 2007. The detailed BEA GSP projections are presented in Tables B-12 through B-18 for all states (excluding the State of Louisiana), and BEA employment growth factors for the State of Louisiana are presented in Table B-19.

Point Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from DOE publication *Annual Energy Outlook 1999*, were applied to the baseline emissions to account for expected increases in fuel and process efficiency in 2007. The adjustment factors are presented in Table B-20.

The CAA controls included in Federal initiatives were applied to the non-utility point sources, as shown in Table B-21. In addition, the MACT controls for NOx and VOC were applied to the non-utilities. The MACT control assumptions are listed in Tables B-22 and B-23.

NO_x SIP Call Control

The emissions controls required by the EPA's Regional NO_x SIP Call were emulated for the point sources located in the modeling domain covered by SIP Call, i.e., the States of Alabama, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, North Carolina, New York, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia and West Virginia, and District of Columbia. The NO_x SIP Call controls were applied to the point sources located north of the 32-degree latitude line in the states of Alabama and Georgia.

The Electric Generation Unit (EGU) and non-EGU point sources subject to the NO_x SIP Call in the point source inventory needed to be identified in order to apply NO_x emissions controls. EPA's " Development of Emissions Budget Inventories for Regional Transport NO_x SIP Call Technical Amendment Version" (EPA, 1999b) provided lists of EGU and non-EGU point sources, and the data were utilized to identify the EGU and non-EGU sources in the point source inventory.

Electric Generating Units (EGUs)

The point sources included in the inventory were matched with the EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The facility name, FIPS code, plant ID, and point ID provided in the EGU data file were used to complete the match. In many cases, the plant and point IDs are not consistent in both inventories. The EGUs in the point source inventory were identified by automated selection of matching the FIPS code and plant ID, followed by detailed manual unit-by-unit matching process. In the end, a small portion of the EGU units in the EPA's data file could not be found in the NEI version 2 point database. However, the major NO_x emitters listed in the EPA's EGU data file were successfully identified in the point source inventory, i.e., all the EGUs located in the States of Alabama, Georgia and Tennessee, and the major NO_x emitters located in the States of Kentucky, Indiana, Illinois, Missouri, North Carolina, South Carolina, Ohio, Pennsylvania, Virginia and West Virginia.

The NO_x control factors for the EGUs were calculated using the 1996 NO_x emission rates (lb/MMBtu) provided in the EPA's EGU data file for each source, and a uniform emission rate of 0.15 lb/MMBtu for the year of 2007.

Non-EGUs

The point sources included in the inventory were matched with the large-size non-EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The FIPS code, plant ID, point ID and Source Classification Codes (SCC) provided in the non-EGU data file were used to complete the match. In some cases, the point IDs are not consistent in both inventories, and non-EGUs in the point source inventory were identified by matching with FIPS, plant ID and SCC. In the end, a small portion of the non-EGU sources in the EPA's data file could not be found in the point source inventory by the FIPS code, plant ID, point ID and SCC matches, although some of the sources may be located outside the modeling domain in the states which are only partially included in the domain.

The NO_x emission reductions were calculated for the large-size non-EGU sources in the specific source categories listed in Table B-24 provided by EPA (EPA, 1999b).

Summary of the Modeling Emission Inventories

The summaries of the 2007 baseline emissions are presented in Appendix B for each modeling episode as follows:

- Table B-25 through Table B-27 for the August/September 1999 episode.
- Table B-28 through Table B-30 for the June 2001 episode.
- Table B-31 through Table B-33 for the July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are tons per day.

Figure 7-1 presents component emission totals for NOx, VOC, and CO for Grid 3 for a typical weekday (18 June 2001) comparing the current year 2001 emissions with the 2007 baseline emissions. For Grid 3, the expected changes in emissions in 2007 result in a 26 percent reduction in anthropogenic NOx emissions, a 16 percent reduction in anthropogenic VOC emissions, and a 17 percent reduction in CO emissions. Figures 7-2 through 7-6 present total emissions for each of the EAC areas for 2001 and 2007. These plots are presented using the same scale so that the totals can be compared between the EAC areas.

Future-Year Boundary Conditions Preparation

For the future-year modeling analysis, with the exception of the emission inventories (and the boundary conditions which are “self-generating”), all inputs for the future-year simulations are identical to those for the corresponding base-case simulation. Through use of the “self-generating” ozone boundary conditions technique (as discussed in Section 5), the boundary condition values for ozone were also indirectly modified for the future-year scenarios. The baseline ozone values used for the boundary conditions are typically 1 to 2 ppb lower than the base-case values, depending upon the simulation day.

Future-Year Baseline Simulation Results

As outlined above, the ATMOS EAC future-year baseline simulation incorporates the effects of population and industry growth (or, in some cases, decline) as well as national or statewide control measures or programs that are expected to be in place by 2007. Only the emissions inputs were directly modified for the future-year baseline simulation. However, through use of the “self-generating” ozone boundary conditions technique, the boundary condition values for ozone were also indirectly modified for the future-year scenarios.

The baseline simulation results provide the starting point for assessment of the effects of further emission reductions on future ozone air quality. The future-year baseline simulation results for Grid 3 indicate both increases and decreases in maximum 8-hour ozone relative to the base-case simulation. There are widespread decreases and isolated areas of increase. The magnitude and pattern of the differences vary from day to day.

Table 7-1 summarizes the results of the 2007 baseline simulation, as illustrated by four 8-hour and 1-hour metrics. The results are provided for Grid 3 and for all of the EAC areas using all of the non-startup days for the three episodes. The results indicate that with the expected reductions in emissions in 2007, there is a 45 to 80% reduction in the value of these metrics compared to the 2001 simulation. The reductions vary across the EAC areas.

Another metric that is important in assessing and demonstrating simulated attainment in the future year is the estimated design value (EDV). Table 7-2 presents the maximum EDV's for each of the EAC areas. These are presented for the monitoring sites within each area where the maximum observed DV occurs for the 2000-2002 and 2001-2003 periods. The EDV's are calculated for concentrations within 15-km of the monitoring site and within the 9 grid-cell area surrounding the site. For the Knoxville EAC, the EDV's are calculated for the local Knoxville site (Spring Hill) and for a site located in the adjacent Great Smoky Mountains area (Clingman's Dome), which is an elevated site. Using the 2000-2002 observed DV, two of the six EAC areas show EDVs less than or equal to 84 ppb for the 2007 baseline simulation. According to EPA guidance, the 2000-2002 DVs should be used in calculating the EDVs, since 2001 is the current year. When the 2001-2003 DVs are used, four of the six EAC areas show calculated EDV's of less than or equal to 84 ppb.

Emission Tagging Simulations

For the ATMOS EAC modeling analysis, the OPTM approach was used to examine the contributions from selected emission source regions and source categories to simulated ozone for the 2007 baseline simulation within and surrounding each of the EAC areas. Emissions from specific areas within the modeling domain and corresponding to specific source categories were tracked using separate tags.

Overview of the Ozone and Precursor Tagging Methodology (OPTM)

Ozone modeling has been used for many years to assist in developing emissions control strategies that effectively reduce ozone. Sensitivity simulations, in which some emissions are omitted from the model input files, are often used to estimate the contribution of various categories of emissions or source regions on simulated ozone concentrations. These are generally referred to as "zero-out" sensitivity simulations. All other inputs are typically the same as for the baseline simulation. The change in ozone is then interpreted as the amount of ozone attributed to the particular emissions category.

Modelers have recognized some drawbacks to the sensitivity simulation methodology for estimating ozone contributions. First of all, a separate simulation must be set up and run for each category that is to be investigated. Second, since the response of the ozone chemistry may be quite non-linear for significant changes in the emissions, the estimated change in ozone may be valid for only the specific change in emissions that was simulated. That is, if the elimination of a category of emissions resulted in a 20 ppb change in ozone, it does not necessarily follow that elimination of half that amount of emissions would result in a 10 ppb change in ozone.

In order to augment the information available from sensitivity simulations, we developed the Ozone and Precursor Tagging Methodology (OPTM). OPTM provides estimates of the contribution of emissions from specified source categories or source regions to the simulated ozone concentrations. The estimates are made for the existing conditions within the simulation and do not require that the system be perturbed (e.g., zeroed out) in order to make the estimate. In addition, estimates for several categories can be made in a single simulation.

Ozone exists in the atmosphere in a dynamic equilibrium with NO and NO_2. NO_2 is photolyzed by sunlight to form NO and a free oxygen atom that combines with an oxygen molecule to form ozone. The ozone and NO recombine rapidly to reform the NO_2 and oxygen molecules. Since it is the oxidized form of the molecules that contribute directly to the ozone present at a given time, a useful quantity to consider is the amount of oxidant present, the sum of NO_2 and ozone. While ozone may drop rapidly when fresh NO emissions are added to the system, the amount of oxidant varies more slowly. When the NO emissions are added, ozone is converted to NO_2, but the sum of NO_2 and ozone stays the same. The amount of oxidant present varies slowly, increasing due to the interaction of VOCs, NO_x and sunlight, and decreasing through removal processes such as deposition and conversion to nitric acid. The OPTM system tracks the amount of oxidant (the sum of NO_2 and ozone) formed from various tagged source categories as a method of estimating the contributions to ozone.

In order to estimate the contributions to ozone, OPTM sets up several new tracer species in a simulation that are used to tag emissions or chemical products. The total emissions of VOC and NO_x from the desired categories are tagged. For illustration, we will assume that there are two categories (Category 1 and Category 2), with VOC-1 and NOX-1 and VOC-2 and NOX-2 corresponding to the two categories. In addition to these emissions tracers, oxidant tracers called OXN-1, OXV-1, OXN-2, and OXV-2 are added. These correspond to the oxidant produced from NO_x and VOC in each of the two categories.

All of the tracers are advected (transported throughout the domain) in the same manner as the other modeled species. They also undergo deposition, but a deposition velocity is not calculated for the tracers. Instead, the fractional change of oxidant (meaning NO2 + O3) is calculated due to the effects of deposition, and this same fractional change is applied to the oxidant tracers. Similarly, the VOC and NO_X tracers are adjusted according to the change in the total VOC and NO_X.

A crucial step in the OPTM system is the calculation of the change in oxidant during the chemistry step of the model. Prior to the chemistry step, total VOC, total NO_X, and total oxidant are calculated. The chemistry step is then called as usual, using the standard CB-V species (NO, NO_2, O_3, PAR, OLE, TOL, etc.). After the chemistry step, new values of total VOC, NO_X, and oxidant are calculated so that the change in VOC, NO_X, and oxidant (ΔVOC, ΔNOX, and ΔOX) can be calculated.

The change in OXN-1 is ΔOX*NOX-1/(NOX-1 + NOX-2), where the NOX-1 and NOX-2 values correspond to the beginning of the time step. Similarly, the change in OXV-1 is ΔOX*VOC-1/(VOC-1 + VOC-2). The same calculations are made for the Category 2 tracers.

The changes in the VOC and NOX tracers are also calculated. The change in VOC-1 is ΔVOC/VOC * VOC-1 and the change in NOX-1 is ΔNOX/NOX*NOX-1, with corresponding calculations for the Category 2 tracers.

The simulation proceeds as usual from this point.

After the simulation is complete, the ozone attributed to a source category is calculated using both the calculated ozone concentration and the oxidant tracer concentrations, as follows:

- Ozone attributed to Category 1 NO_x = O3*OXN-1/(OXN-1 + OXN-2).
- Ozone attributed to Category 2 NO_x = O3*OXN-2/(OXN-1 + OXN-2).
- Ozone attributed to Category 1 VOC = O3*OXV-1/(OXV-1 + OXV-2).
- Ozone attributed to Category 2 VOC = O3*OXV-2/(OXV-1 + OXV-2)..

The OPTM tags can be defined to represent geographic areas or assigned to categories of emissions (such as mobile, elevated point source, low-level, etc.) There is no explicit limit to the number of VOC or NO_x tags that can be set up within a single simulation.

ATMOS OPTM Results

The ATMOS EAC modeling analysis included three sets of tagging simulations, which tracked contributions to ozone from different emissions sources and source regions. For the August 1999 and July 2001 episodes, the 2007 baseline run was redone under each of three scenarios, called AT-1, AT-2, & AT-3. For the AT-3 scenario, a third episode (July 2002) was also simulated. The specific tags for each scenario are as follows:

SCENARIO AT-1:

- On-road mobile source emissions from five EAC areas (Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities).
- Other low-level emissions from the five EAC areas.
- Elevated point source emissions from all point sources in Tennessee and all TVA sources.
- All other emissions, including biogenic emissions.

SCENARIO AT-2:

- Anthropogenic emissions from Shelby County, TN sources.
- Anthropogenic emissions from Crittenden County, AR sources.
- Anthropogenic emissions from DeSoto County, MS sources.
- All other emissions (including all biogenic emissions).

SCENARIO AT-3:

- Anthropogenic emissions from the Atlanta 45-county area.
- Anthropogenic emissions from the Birmingham 2-county area.
- All other anthropogenic emissions from the Grid 3.
- All other anthropogenic emissions.
- All biogenic emissions.

In each case, NO_x and VOC emissions are tagged explicitly and each scenario also included an additional tag for all emissions not otherwise tagged in that scenario. In total, the first ATMOS tagging scenario provided a comparison of contribution from anthropogenic emissions from the five EAC areas for three source categories (on-road, elevated, and low-level emissions), the second compared the contribution of emissions from three counties within the Memphis EAC area, and the third tracked emissions from the Atlanta and Birmingham areas, areas within Grid 3, in all other regions in the modeling domain, and from biogenic sources. These simulations provided information regarding the relative contribution of the emissions to observed and simulated ozone in the EAC areas by geographic area and source category as well as the effects of emissions from outside the areas of interest, and was used to guide the selection of control measures (e.g., NO_x vs. VOC controls) based on their expected relative effectiveness in reducing ozone in the EAC areas.

For the AT-1 simulation, Figure 7-7 provides an example of the contributions of each of the tagged source categories for NO_x and VOC emissions on simulated 8-hour ozone exceedance exposure in the Memphis EAC area. This figure is a combination of all non-start-up days for the two episodes. The figure indicates that NO_x emissions from mobile sources and other low-level sources contribute equally to ozone exceedance for the combined August 1999 and July 2001 periods, and that NO_x from TVA and other elevated sources contributes less. For VOC emissions, the low-level sources contribute more to ozone exposure than the mobile or elevated sources. The largest contributor to ozone exceedance exposure in the Memphis EAC area is contributions from biogenic emissions within or around the area or other sources outside the EAC area. As a second example, Figure 7-8 presents contributions in the Nashville EAC area. Contributions from low-level NO_x emissions are somewhat smaller for the Nashville area.

The results for the AT-1 simulation can be summarized as follows:

- On-road mobile source NO_x emissions are important contributors for all areas.
- Other low-level NO_x emissions contribute less than on-road mobile, but other low-level VOC emissions tend to be more important than mobile VOCs.
- Contribution from elevated NO_x is typically less than that for on-road mobile but greater than that for other low-level NO_x sources.
- Relative contributions to the maximum 8-hour ozone value varies from day to day.
- The contribution from all other (including biogenic) sources ranges from about 50 – 80% for NO_x and from about 80-100% for VOC.

For the AT-2 simulation, Figure 7-9 shows the contribution in Shelby County from anthropogenic emissions located in Shelby, Crittenden, and DeSoto Counties. The largest contributor to ozone exceedance exposure in Shelby County among the tagged emissions is from emissions in Shelby County, with much smaller contributions for emissions in Crittenden and DeSoto Counties. Figure 7-10 shows the contribution in Crittenden County from anthropogenic emissions located in Shelby, Crittenden, and DeSoto Counties. The largest contributor to ozone exceedance exposure in Crittenden County is from emissions in Shelby County, with smaller contributions for emissions in Crittenden and DeSoto Counties. The results for the AT-2 simulation can be summarized as follows:

- For the ATMOS simulation days, emissions from Shelby Co. contribute to 8-hour ozone in Shelby, Crittenden, and DeSoto Co.
- Local (same-county) emissions are also important, especially during peak 8-hour ozone periods.
- Background and transported ozone and precursors are important factors for all three counties.

For the AT-3 scenario, emissions in the Greater Atlanta area, the Birmingham area, the rest of Grid 3, the area outside of Grid 3, and biogenic emissions, were all tagged separately. The AT-3 scenario was run for all three ATMOS episodes. Figure 7-11 depicts the contribution of NO_x and

VOC emissions from these areas/source categories to 8-hour ozone exceedance exposure for the Chattanooga EAC area. For these episodes, there is some contribution to 8-hour ozone exceedance in this area from the Atlanta-area NO_x emissions. There is also a significant contribution from NO_x emissions within Grid 3, and an even larger contribution from sources outside of Grid 3. For VOC emissions, there is a very slight contribution from the Atlanta area, with the largest contributors being sources outside Grid 3 and biogenic sources. Figure 7-12 shows the contribution to simulated 8-hour maximum concentrations at the Sequoyah monitor, located in Chattanooga, at three different simulation times. The pie charts depict the contributions from each of the tagged emissions. For these dates and times, the contribution from the Atlanta area NOx emissions is fairly significant, contributing 11 to 21 percent of the simulated 8-hour maximum concentration for these periods. The contribution from NO_x emissions outside of Grid 3, however, dominates for these periods. For VOC emissions, the contribution from biogenic emissions is comparable to that of VOCs from outside of Grid 3. The results of the AT-3 simulation can be summarized as follows:

- Emissions from the Atlanta metropolitan area contribute to ozone exceedances in Knoxville and Chattanooga.
  - Of the NO_x contributing to the 8-hour exceedance exposure, about 20% overall is attributed to emissions from Atlanta.
  - Of the NO_x contributing to the peak 8-hour values, about 5-15% is attributed to Atlanta on certain exceedance days.
- Background and transported ozone and precursors are important factors for all areas.
- Approximately 40 to 60% of the ozone is attributed to biogenic VOC emissions.

Attainment-Strategy Simulations

The ambitious EAC schedule precluded an extensive emission-reduction sensitivity analysis using the 2007 baseline inventory. However, in the previous phase of ATMOS, a number of emission reduction sensitivity simulations were conducted for a 2010 baseline. The results of these simulations indicated the following: 1) reductions of NOx emissions are more effective in reducing ozone concentrations than similar percentage reductions in VOC emissions, 2) local emission reductions are more effective in reducing local ozone concentrations, and 3) the ATMOS EAC areas are affected, to some extent, by precursor emissions and ozone formed outside the areas, and the extent of the contribution varies from day to day and among the EAC areas.

Between 2001 and 2007, the expected emission reductions showed significant reductions in the simulated 1-hour and 8-hour ozone metrics, however, based on the calculated EDVs, the 2007 baseline simulation did not show simulated attainment for all EAC areas. Thus, more reductions are required for these areas. On the basis of the information derived from the 2010 emission reduction sensitivity analysis and the OPTM tagging simulations, a series of attainment strategy simulations were identified and conducted for the three ATMOS modeling episodes. Representatives from each of the areas first prepared a list of potential local EAC control measures. For the Tennessee EAC areas, the University of Tennessee (UT) provided assistance in identifying and quantifying the EAC measures. A summary of the potential measures for the Nashville EAC is presented by UT (2003). The list of potential measures is presented in Table 7-3.

Prior to having the measures selected by each of the groups, a strategy sensitivity simulation was conducted to assess the sensitivity to emission reductions in each of the EAC counties. This scenario, referred to as AS-1, involved the following reductions: a 5% reduction in all anthropogenic sources of NO_x, VOC, and CO in all EAC counties with the following exceptions: Chattanooga EAC reductions of 5% coming from area sources only, and for Davidson County of the Nashville EAC, a 5% reduction in area sources, a 1% reduction in low-level point and non-road sources, and a 2% reduction in mobile emissions. This scenario was conducted for the 2007 baseline simulations of the August 1999 and June 2001 episodes. The results for AS-1 indicate that 8-hour exceedance exposure is reduced by 10 percent while EDV's are reduced by about 1 ppb for the Memphis, Nashville, and Knoxville areas and unchanged in the Chattanooga and Tri-Cities areas.

After quantification of the list of potential emission reduction measures, a second strategy simulation has conducted in which reductions were made in all EAC areas reflecting all possible measures from the list. This scenario, AS-2, is referred to as the "all measures" scenario and was conducted for the August 1999 and June 2001 episodes. Figure 7-14 presents NOx and VOC emission totals comparing the 2007 Baseline emissions with the AS-2 emissions. Imposing all potential EAC measures in 2007 results in approximately a 5 to 8 percent reduction in NO_x emissions and as much as a 10 percent reduction in VOC emissions in these areas. The AS-2 simulation resulted in reductions in 8-hour exceedance exposure of from 12 to 50 percent compared to the 2007 baseline, while EDVs are reduced approximately 2 ppb for the Memphis, Knoxville, and Chattanooga area and unchanged for the Nashville and Tri-Cities EAC areas.

Following the AS-2 scenario, each of the EAC areas re-visited the list and the commitments that could be made in each of the EAC counties and in local jurisdictions. The next scenario (AS-3) assessed the effects of a reduced set of measures, which included less emission reductions. The results for AS-3 show model responses between the AS-1 and AS-2 scenarios. Following the AS-3 scenario, the EAC areas prepared a final list of measures that would be adopted as part of the EAC program. This final scenario, AS-4, assessed the effects of a slightly different set of EAC measures than AS-3 and included fewer emission reductions compared to the AS-2 "all measures" scenario.

Table 7-4 presents the local measures selected by each of the EAC areas for the AS-4 attainment strategy scenario. The expected reductions (tpd) are presented for NO_x, VOC, and CO emissions for each county contained in the EAC area. The AS-4 scenario was run for the three ATMOS episodes and the results are presented in the next section of this report.

Table 7-1a.
Comparison of the ATMOS Current Year (2001)
and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	8-hr Exceedance Exposure			# Grid-cells where max 8-hr > 84 ppb		
	2001	2007	% Reduction	2001	2007	% Reduction
Grid 3	4502274	1342820	70	41602	14798	64
Memphis EAC	92093	44429	51	766	460	40
Nashville EAC	208109	65140	69	2079	887	57
Knoxville EAC	140359	24169	83	1358	517	62
Chattanooga EAC	204711	56174	73	1741	693	60
Tri-Cities EAC	60247	18187	70	411	207	50

Table 7-1b.
Comparison of the ATMOS Current Year (2001)
and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	# Grid Cell Hours where 1-Hr Concs > 84 ppb			1-Hr Exceedances Exposure for Concs > 84 ppb		
	2001	2007	% Reduction	2001	2007	% Reduction
Grid 3	388289	151316	61	3800105	1290141	66
Memphis EAC	7514	4227	44	77821	40541	48
Nashville EAC	18777	8752	53	176247	66871	62
Knoxville EAC	11554	5093	56	111972	30180	73
Chattanooga EAC	14858	6453	57	154244	50725	67
Tri-Cities EAC	5015	2382	53	47512	16342	66

Table 7-2.
Maximum Observed and Estimated Design Values (EDVs) for the ATMOS EAC Areas
for the 2007 Baseline Simulation

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Memphis EAC (Marion)	94	89	88	92	87	87
Nashville EAC (Rockland Rd.)	88	81	82	86	79	80
Knoxville EAC (Spring Hill)	96	90	90	92	86	86
Knoxville EAC (Clingman's Dome)	98	89	87	92	84	82
Chattanooga EAC (Sequoyah)	93	86	86	87	80	80
Tri-Cities EAC (Kingsport)	92	85	84	86	79	79

Table 7-3.
List of Potential EAC Emission Reductions Measures for the ATMOS EAC Areas

Area Sources	
Open burning ban -residential garbage	Stage I controls at gas stations
Open burning ban -yard waste	Stage II controls at gas stations
Open burning ban - land clearing	
Onroad Mobile Sources	
Smoking vehicle ban	Cetane Additive to Diesel
HOV lane expansion	Inspection & Maintenance (OBD only) I/M.
Rideshare programs	Inspection & Maintenance OBDII and Idle I/M
Traffic signal synchronization	Intelligent transportation systems
Roadside assistance program	Lower gas RVP (from 9 to 7.8)
New greenways/bikeways	Lower interstate truck speeds by 10 mph
Low emission fleets (on-road)	Ozone Action Day (Reduce VMT 1%)
Reduce school bus idling	Traffic Flow Improvement
Improve bus ridership	Transit (increase bus ridership 5%)
New rail service	Trip Reduction Programs
Land use controls to reduce VMT	Truck stop electrification
Air Quality Action Day measures	Voluntary Control Measures
Anti-idling Legislation	
Nonroad Mobile Sources	
Replace Construction Equipment	New airport vehicles
Point Sources	
50 Ton NOx/Year RACT Rule	

Table 7-4a.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Memphis EAC Area

Control Measures by Source Category	Fayette, TN			Shelby, TN			Tipton, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TP D
Area									
Open Burning Ban - Land clearing	0.000	0.000	0.000	0.300	7.170	13.140	0.000	0.000	0.000
Onroad Mobile									
Intelligent transportation sys (CMAQ Report)	0.000	0.000	0.000	0.159	0.061	0.660	0.000	0.000	0.000
Lower interstate truck speeds by 10 mph.	0.000	0.000	0.000	5.900	0.000	0.000	0.000	0.000	0.000
Anti-idling Legis. (1% veh idle 5 min/day)	0.000	0.000	0.000	0.012	0.012	0.079	0.000	0.000	0.000
Voluntary Control Measures	0.000	0.000	0.000	0.676	0.449	0.833	0.000	0.000	0.000
Point Sources	0.000	0.000	0.000	4.900	0.245	0.000	0.000	0.000	0.000
Reductions by Source Category									
Area	0.000	0.000	0.000	0.300	7.170	13.140	0.000	0.000	0.000
Mobile Source	0.000	0.000	0.000	6.747	0.522	1.572	0.000	0.000	0.000
Elev. Point	0.000	0.000	0.000	4.900	0.245	0.000	0.000	0.000	0.000

Control Measures by Source Category	Crittenden, AR			De Soto, MS		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area						
Open Burning – land clearing/debris	0.000	0.000	0.000	0.175	0.407	5.929
Stage I Controls at Gas Stations.	0.000	0.485	0.000	0.000	0.000	0.000
Nonroad Mobile						
Construction Equipment (All New).	0.110	0.010	0.050	0.000	0.000	0.000
Reductions of Maintenance on Action Days	0.000	0.000	0.000	0.100	0.020	0.400
Onroad Mobile						
Truck stop electrification	0.036	0.003	0.276	0.000	0.000	0.000
Ozone Action Day (Reduce VMT 1%)	0.024	0.032	0.353	0.000	0.000	0.000
Truck idling reductions	0.000	0.000	0.000	0.100	0.050	0.600
Reductions by Source Category						
Area	0.000	0.485	0.000	0.175	0.407	5.929
Mobile Source	0.060	0.035	0.629	0.100	0.050	0.600
Nonroad Mobile	0.110	0.010	0.050	0.100	0.020	0.400

Table 7-4b.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Nashville EAC Area

Control Measure by Source Category	Davidson, TN			Rutherford, TN			Sumner, TN			Williamson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area												
-const. Land clear (open burning).	0.111	0.423	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Onroad Mobile												
-HOV lane expansion	0.012	0.015	0.174	0.005	0.006	0.071	0.000	0.000	0.000	0.000	0.000	0.000
-trip reduction plans	0.040	0.051	0.578	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.017	0.193
-rideshare programs	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014
-traffic signal synchronization	0.091	0.110	0.679	0.038	0.050	0.305	0.033	0.038	0.225	0.018	0.023	0.143
-roadside assistance program	0.031	0.031	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-new greenways/bikeways	0.010	0.012	0.140	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105
-reduce school bus idling	0.007	0.001	0.007	0.003	0.000	0.002	0.003	0.000	0.003	0.003	0.000	0.002
-improve bus ridership	0.010	0.012	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-new rail service	0.021	0.037	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-land use controls to reduce VMT	0.260	0.110	1.340	0.090	0.030	0.360	0.040	0.020	0.210	0.050	0.020	0.260
-AQAD measures	0.510	0.220	2.680	0.170	0.060	0.720	0.080	0.040	0.410	0.110	0.040	0.510
Reductions by Source Category												
Area	0.111	0.423	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Onroad Mobile	0.992	0.600	6.504	0.314	0.157	1.577	0.164	0.108	0.966	0.202	0.110	1.226

Control Measure by Source Category	Wilson, TN			Cheatham, TN			Dickson, TN			Robertson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Onroad Mobile												
-rideshare programs	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014
-traffic signal synchronization	0.015	0.018	0.105	0.000	0.000	0.000	0.008	0.015	0.080	0.005	0.008	0.050
-new greenways/bikeways	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105
-reduce school bus idling	0.002	0.000	0.002	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001
-new rail service	0.021	0.037	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-land use controls to reduce VMT	0.050	0.020	0.210	0.030	0.010	0.130	0.030	0.020	0.160	0.060	0.020	0.210
-AQAD measures	0.110	0.030	0.430	0.060	0.020	0.270	0.060	0.030	0.330	0.120	0.030	0.430
Reductions by Source Category												
Onroad Mobile	0.206	0.115	1.285	0.100	0.041	0.520	0.107	0.076	0.690	0.195	0.068	0.810

Table 7-4c.
Emissions Reductions the AS-4 EAC Attainment Strategy: Knoxville EAC Area

Control Measure by Source Category	Anderson, TN			Blount, TN			Jefferson, TN			Knox, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area												
Open Burning Ban –residential garbage	0.012	0.015	0.178	0.019	0.022	0.265	0.008	0.009	0.111	0.000	0.000	0.000
Open Burning Ban -yard waste	0.003	0.019	0.100	0.005	0.028	0.148	0.002	0.012	0.062	0.000	0.000	0.000
Open Burning Ban - land clearing	0.178	0.692	4.700	0.265	1.026	4.800	0.111	0.430	3.200	0.955	3.706	21.500
Nonroad Mobile												
Construction Equipment (14.3 % New).	0.014	0.002	0.006	0.027	0.003	0.011	0.019	0.002	0.008	0.140	0.017	0.063
Onroad Mobile												
Truck stop electrification, 30% occupancy	0.012	0.001	0.011	0.000	0.000	0.000	0.171	0.016	0.144	0.300	0.029	0.253
Transit (increase bus ridership 5%)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.012
Trip Reduction Programs	0.000	0.000	0.000	0.019	0.025	0.000	0.000	0.000	0.000	0.091	0.125	0.000
Traffic Flow Improvement	0.005	0.005	0.000	0.007	0.007	0.000	0.004	0.004	0.000	0.017	0.018	0.000
Ozone Action Day (Reduce VMT 1%)	0.027	0.035	0.393	0.032	0.041	0.463	0.028	0.037	0.414	0.157	0.204	2.281
Point												
50 Ton NOx/Year RACT Rule												
Becromal & Chestnut Landfill	0.350	0.000	0.000									
Alcoa				0.500	0.000	0.000						
UT, St. Marys, Tamko, TSD, & CEMEX										1.580	0.013	0.280
Kimberly Clarke & Trigen; Staley & Viskase												
Dan River												
Reductions by Source Category												
Area Sources	0.194	0.725	4.978	0.288	1.076	5.213	0.120	0.451	3.373	0.955	3.706	21.500
Onroad Mobile	0.044	0.041	0.404	0.057	0.074	0.463	0.203	0.057	0.558	0.567	0.376	2.546
Nonroad Mobile	0.014	0.002	0.006	0.027	0.003	0.011	0.019	0.002	0.008	0.140	0.017	0.063
Elev. Point	0.350	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	1.580	0.000	0.280

Table 7-4c.
Emissions Reductions the AS-4 EAC Attainment Strategy: Knoxville EAC Area *(continued)*

Control Measure by Source Category	Loudon, TN			Sevier, TN			Union, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.007	0.008	0.098	0.012	0.015	0.178	0.003	0.004	0.045
Open Burning Ban -yard waste	0.002	0.010	0.055	0.003	0.019	0.100	0.001	0.005	0.025
Open Burning Ban - land clearing	0.098	0.379	1.900	0.178	0.690	3.200	0.045	0.173	1.100
Nonroad Mobile									
Construction Equipment (14.3 % New).	0.007	0.001	0.003	0.033	0.004	0.015	0.002	0.000	0.000
Onroad Mobile									
Truck stop electrification, 30% occupancy	0.129	0.012	0.109	0.026	0.002	0.022	0.000	0.000	0.000
Traffic Flow Improvement	0.003	0.003	0.000	0.007	0.008	0.000	0.001	0.001	0.000
Ozone Action Day (Reduce VMT 1%)	0.024	0.032	0.353	0.032	0.041	0.462	0.004	0.005	0.056
Point									
50 Ton NOx/Year RACT Rule									
Becromal & Chestnut Landfill									
Alcoa									
UT, St. Marys, Tamko, TSD, & CEMEX									
Kimberly Clarke & Trigen; Staley & Viskase	3.550								
Dan River				0.190					
Reductions by Source Category									
Area Sources	0.106	0.398	2.052	0.194	0.724	3.478	0.048	0.181	1.169
Onroad Mobile	0.156	0.047	0.461	0.065	0.051	0.484	0.005	0.006	0.056
Nonroad Mobile	0.007	0.001	0.003	0.033	0.004	0.015	0.002	0.000	0.000
Elev. Point	3.550	0.000	0.000	0.190	0.000	0.000	0.000	0.000	0.000

Table 7-4d.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Chattanooga EAC Area

Control Measures by Source Category	Hamilton, TN			Marion, TN			Meigs, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TP D
Area									
Open Burning Ban -yard waste	0.140	0.506	9.600	0.000	0.000	0.000	0.000	0.000	0.000
Open Burning Ban - Land clearing	0.440	1.102	6.320	0.000	0.000	0.000	0.000	0.000	0.000
Stage I Controls at Gas Stations	0.000	2.468	0.000	0.000	0.485	0.000	0.000	0.058	0.000
Nonroad Mobile									
Construction Equipment (10% New)	0.053	0.007	0.024	0.008	0.001	0.004	0.001	0.001	0.005
Onroad Mobile									
Cetane to Diesel (-3% NOx)(10% effective)	0.110	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000
Anti-idling Legis. (1% veh idle 5 min/day)	0.004	0.004	0.027	0.000	0.000	0.002	0.000	0.000	0.001
Transit (increase bus ridership 10%)	0.003	0.004	0.043	0.000	0.000	0.000	0.000	0.000	0.000
Ozone Action Day (Reduce VMT 1%)	0.124	0.161	1.796	0.024	0.032	0.353	0.003	0.004	0.042
Reductions by Source Category									
Area	0.580	4.076	15.920	0.005	0.485	0.000	0.000	0.058	0.000
Onroad Mobile	0.241	0.157	1.866	0.064	0.028	0.355	0.003	0.004	0.043
Nonroad Mobile	0.053	0.007	0.024	0.008	0.001	0.004	0.001	0.001	0.005

Control Measures by Source Category	Catoosa, GA			Walker, GA		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area						
Open Burning Ban -residential garbage	0.040	0.194	0.120	0.050	0.218	0.150
Open Burning Ban -yard waste	0.000	0.000	0.000	0.003	0.016	0.085
Open Burning Ban - land clearing	0.370	1.102	4.870	0.000	0.000	0.000
Stage I Controls at Gas Stations	0.000	0.000	0.000	0.000	0.323	0.000
Nonroad Mobile						
Construction Equipment (10% New)	0.006	0.001	0.003	0.012	0.001	0.005
Onroad Mobile						
Anti-idling Legis. (1% veh idle 5 min/day)	0.001	0.001	0.005	0.001	0.001	0.005
Ozone Action Day (Reduce VMT 1%)	0.024	0.031	0.342	0.016	0.021	0.235
Reductions by Source Category						
Area	0.410	1.296	4.990	0.053	0.557	0.235
Onroad Mobile	0.024	0.029	0.346	0.017	0.021	0.240
Nonroad Mobile	0.006	0.001	0.003	0.012	0.001	0.005

Table 7-4e.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Tri-Cities EAC Area

Control Measure by Source Category	Carter, TN			Hawkins, TN			Johnson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.049	0.060	0.700	0.060	0.070	0.860	0.030	0.037	0.440
Open Burning Ban -yard waste	0.002	0.013	0.071	0.003	0.016	0.087	0.001	0.008	0.044
Open Burning Ban - land clearing	0.074	0.272	0.650	0.070	0.257	1.500	0.023	0.084	0.700
Ozone Action Day (Reduce VMT 1%)	0.023	0.025	0.230	0.022	0.024	0.220	0.007	0.007	0.070
Reductions by Source Category									
Area	0.148	0.370	1.651	0.154	0.367	2.667	0.061	0.136	1.254

Control Measure by Source Category	Sullivan, TN			Unicoi, TN			Washington, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.076	0.092	1.100	0.022	0.026	0.031	0.063	0.077	0.890
Open Burning Ban -yard waste	0.003	0.020	0.108	0.001	0.006	0.031	0.003	0.017	0.091
Open Burning Ban - land clearing	0.199	0.735	9.183	0.023	0.085	1.060	0.139	0.515	2.300
Ozone Action Day (Reduce VMT 1%)	0.120	0.090	0.900	0.010	0.010	0.100	0.075	0.060	0.570
Reductions by Source Category									
Area	0.398	0.937	11.291	0.056	0.127	1.222	0.280	0.668	3.851

Figure 7-1a.
Comparison of NOx Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

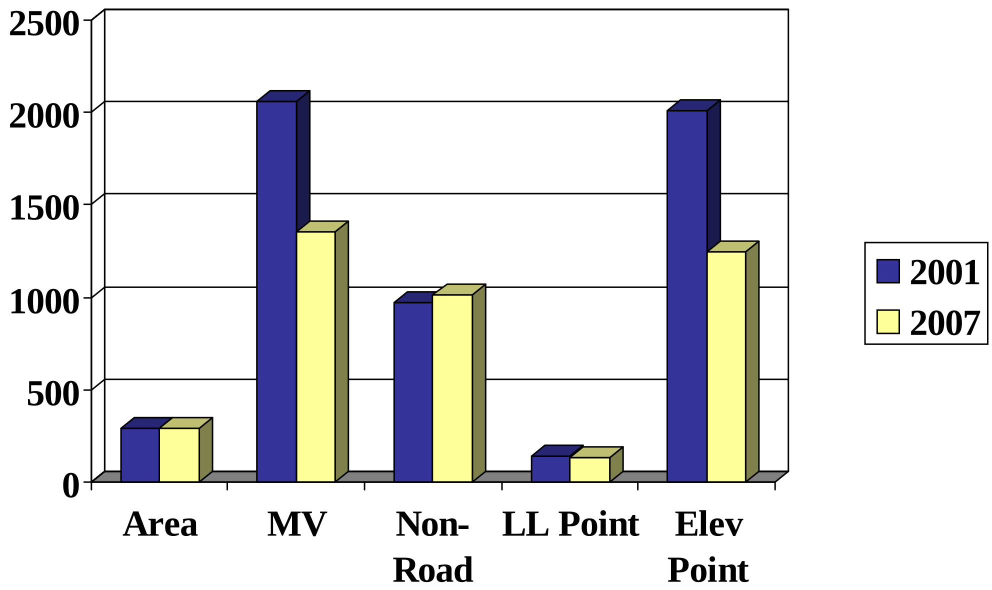


Figure 7-1b.
Comparison of VOC Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

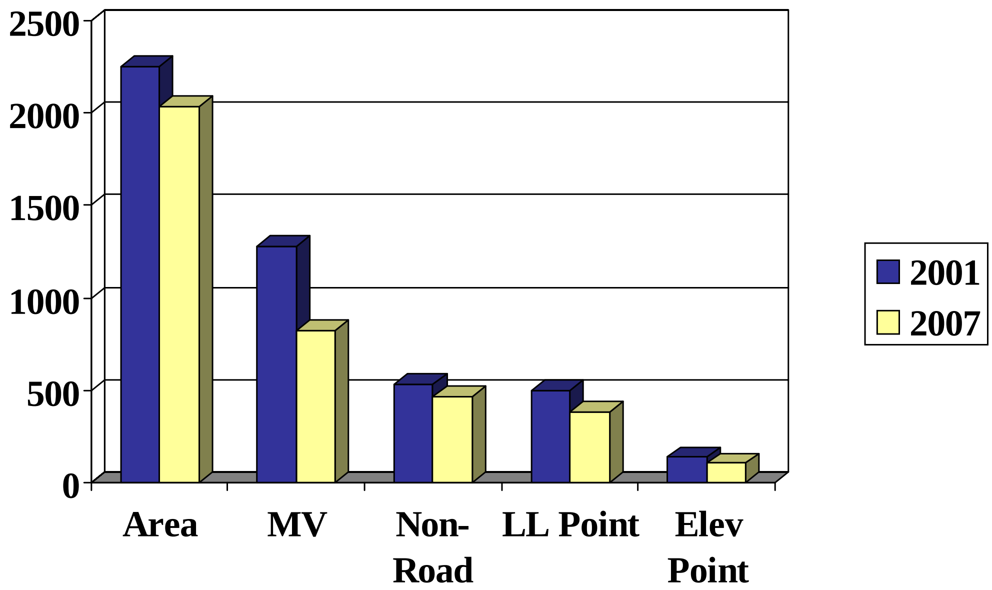


Figure 7-1c.
Comparison of CO Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

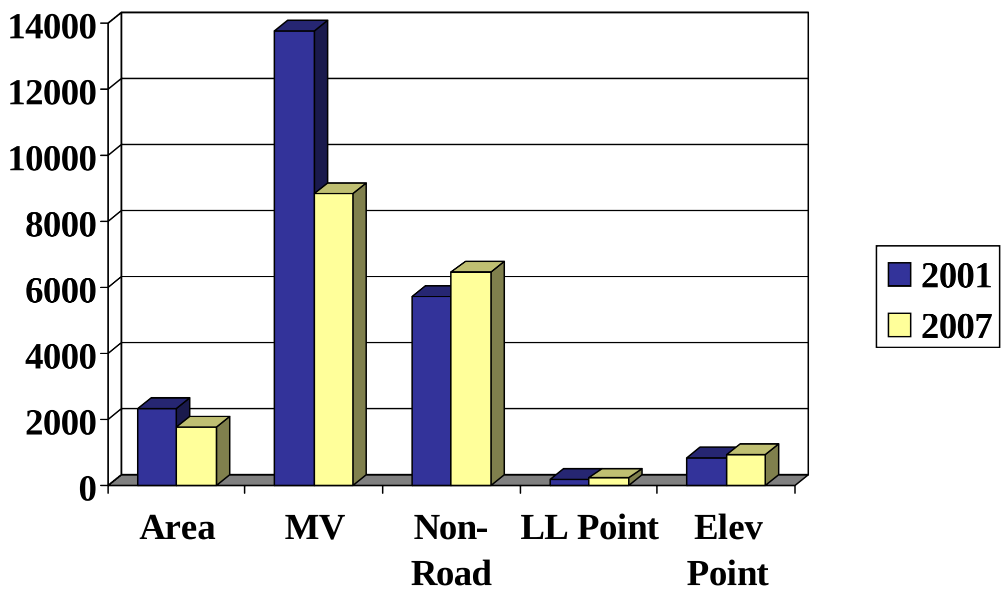


Figure 7-2.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

Emissions for 18 June Episode Day

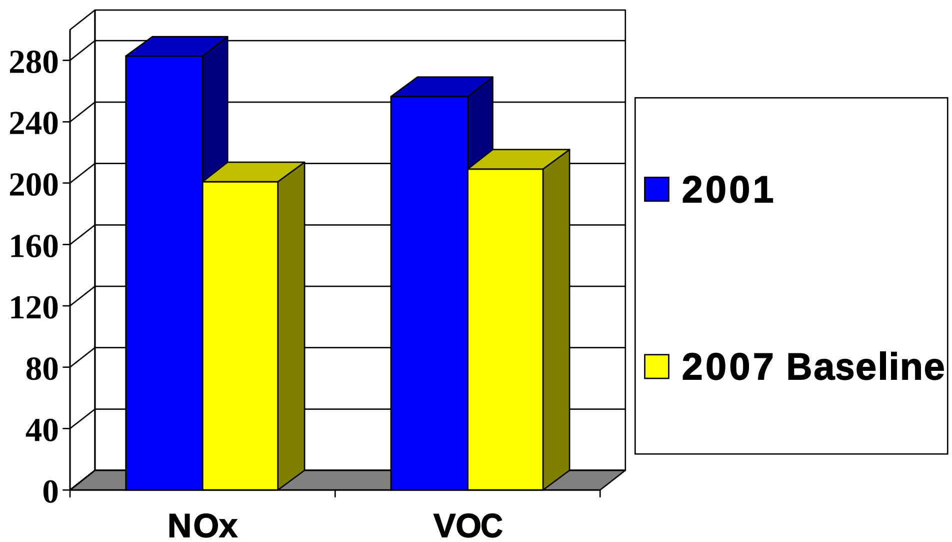


Figure 7-3.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

Emissions for 18 June Episode Day

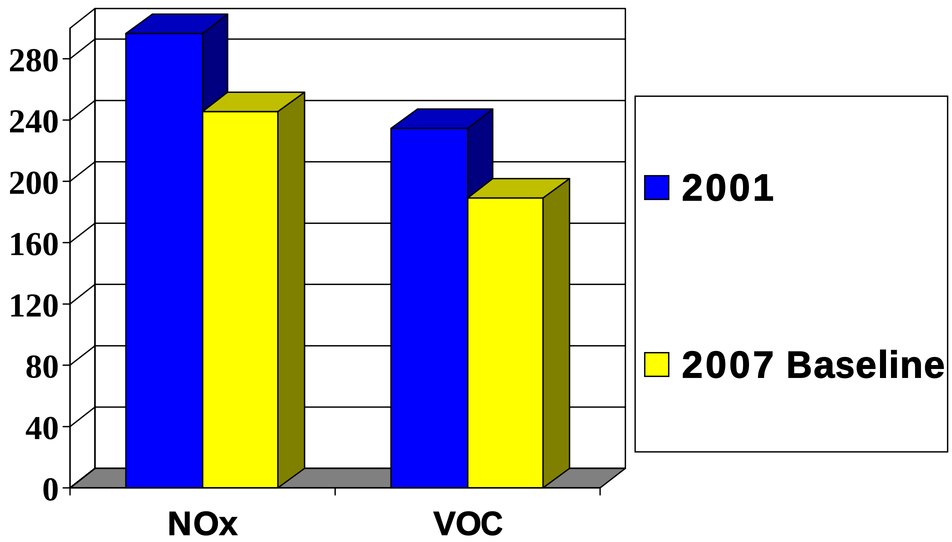


Figure 7-4.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

Emissions for 18 June Episode Day

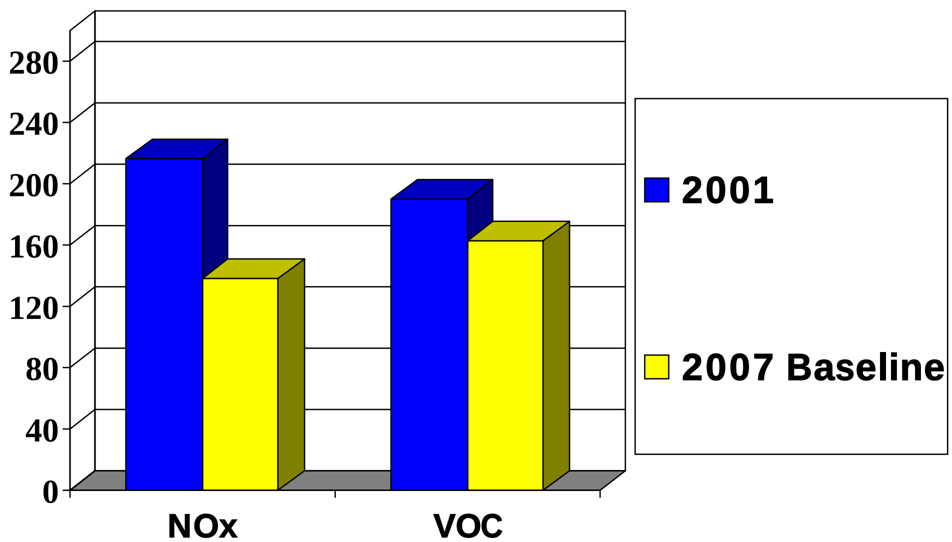


Figure 7-5.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

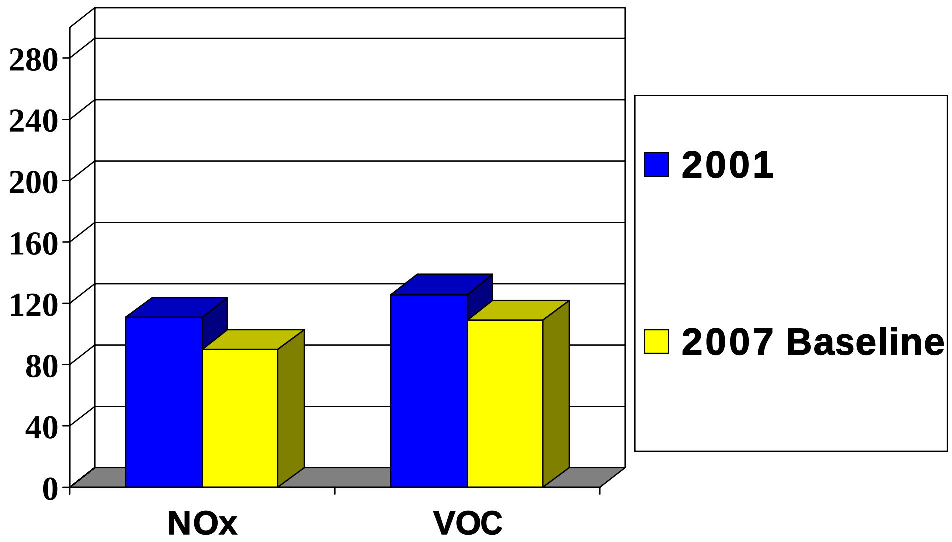


Figure 7-6.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area

Emissions for 18 June Episode Day

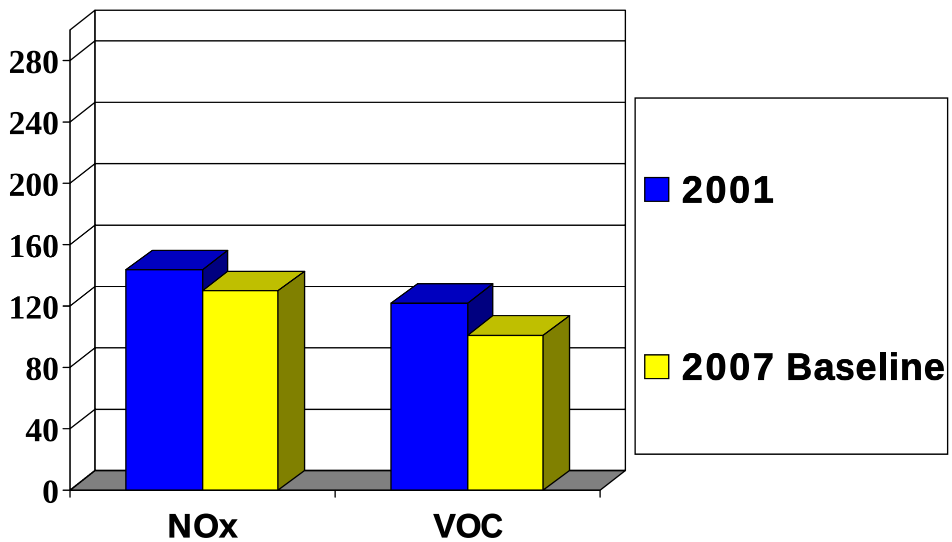


Figure 7-7.
Contribution from NOx and VOC Emissions to Total 8-hour Ozone Exceedance Exposure in the Memphis EAC Area

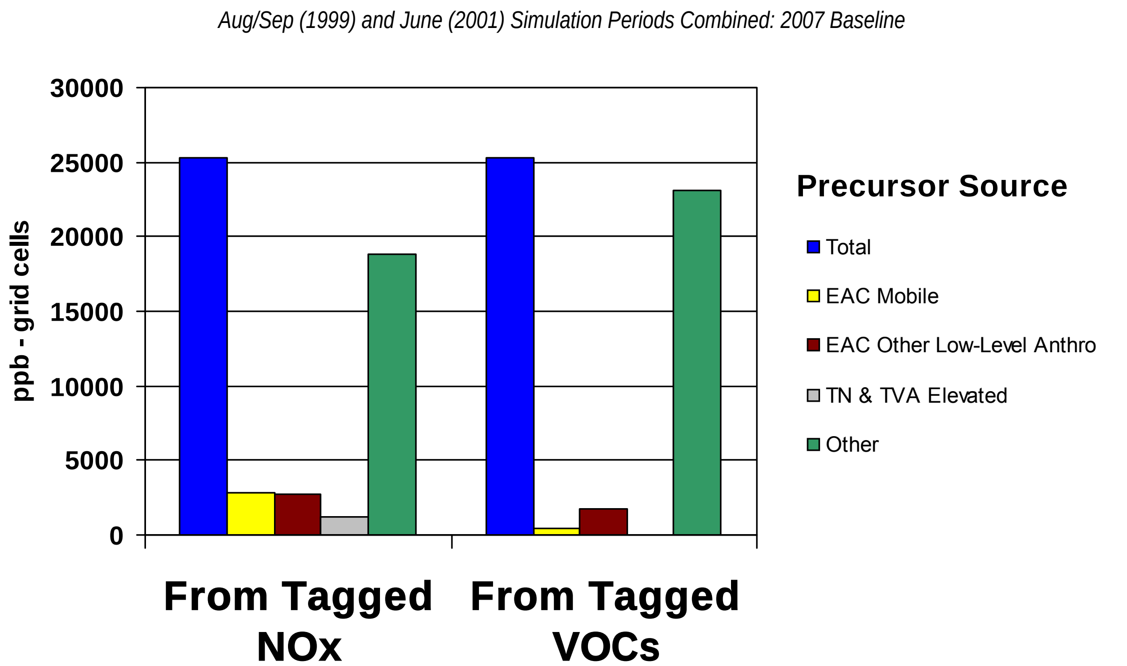


Figure 7-8.
Contribution from NOx and VOC Emissions to Total 8-hour Ozone Exceedance Exposure in the Nashville EAC Area

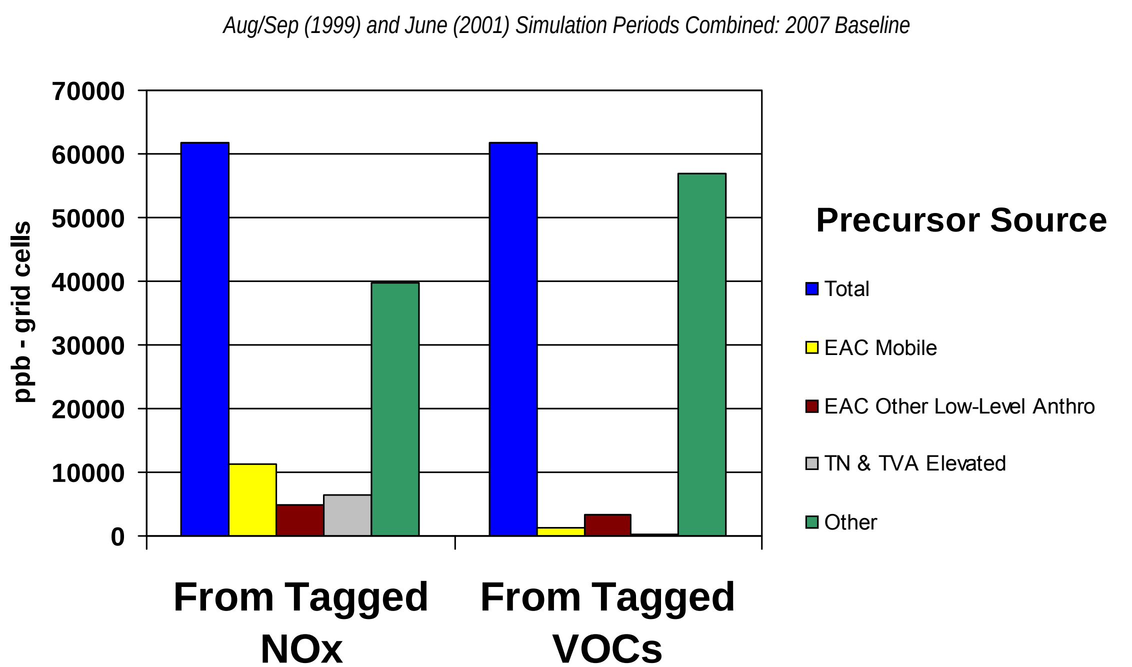


Figure 7-9.
Contribution from NOx and VOC Emissions in Shelby, Crittenden, and DeSoto Counties to Total 8-hour Ozone Exceedance Exposure in Shelby County, TN

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

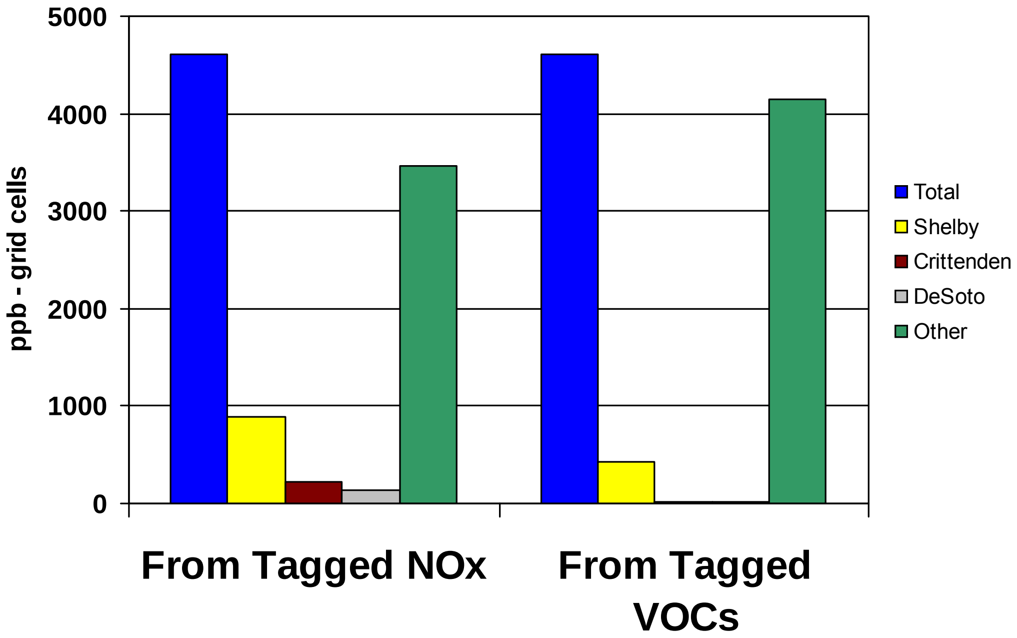


Figure 7-10.
Contribution from NOx and VOC Emissions in Shelby, Crittenden, and DeSoto Counties to Total 8-hour Ozone Exceedance Exposure in Crittenden County, AR

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

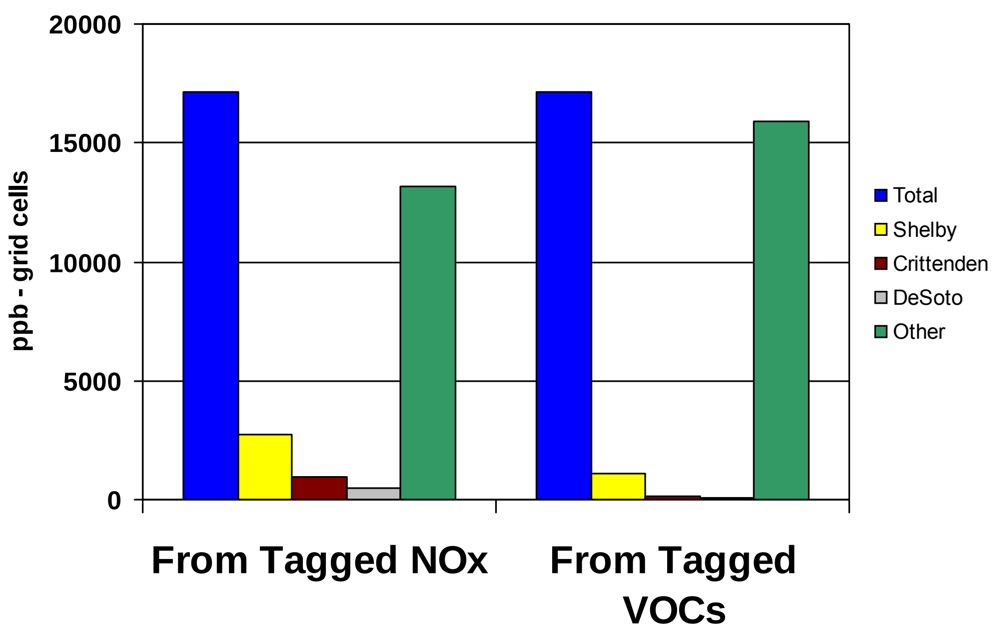


Figure 7-11.
Contribution from NOx and VOC Emissions in Atlanta, Birmingham, within Grid 3, and Outside Grid 3 to Total 8-hour Ozone Exceedance Exposure in the Chattanooga EAC Area

Aug/Sep (1999), June (2001), and July (2002) Simulation Periods Combined: 2007 Baseline

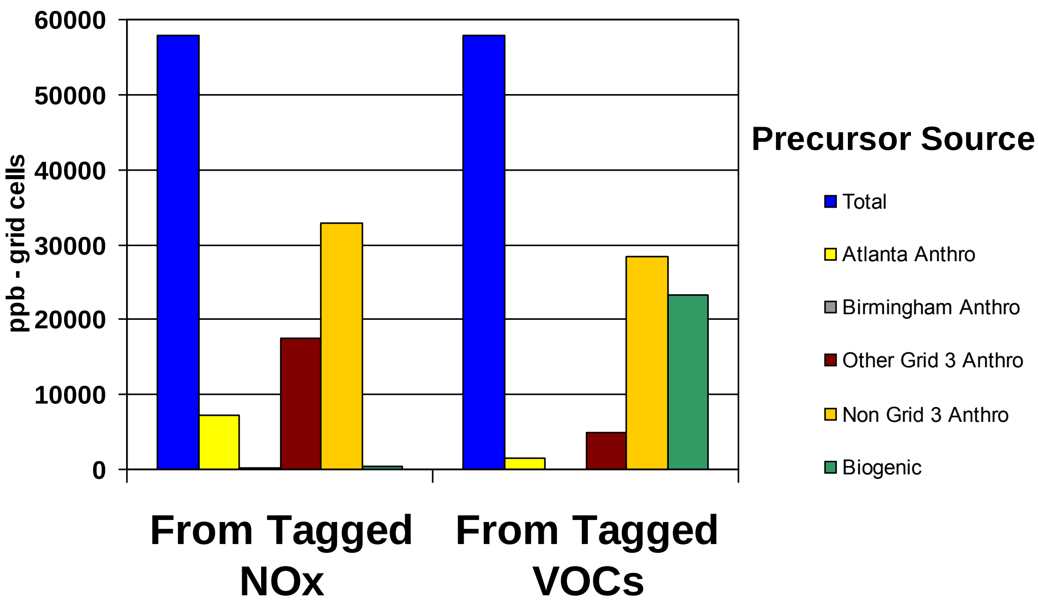


Figure 7-12.
Relative Contribution from Regional VOC and NOx Emissions to Simulated 8-hour Maximum Ozone Concentration at the Sequoyah Monitor (Chattanooga) for Three Different 8-Hour Periods

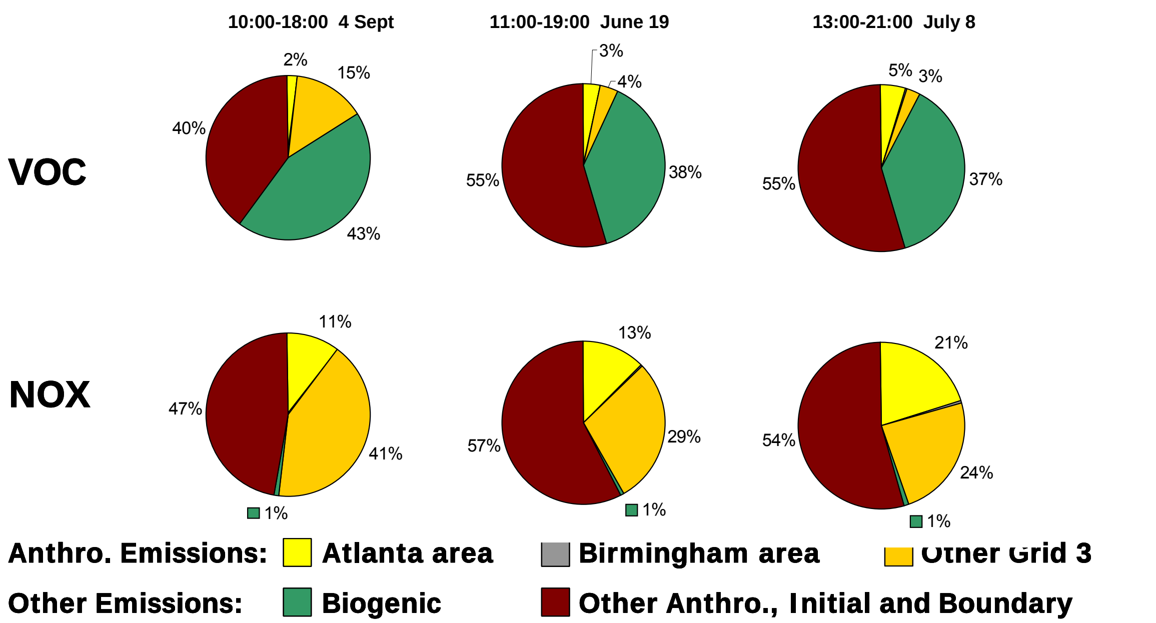


Figure 7-13.
Contribution from NOx and VOC Emissions in Atlanta, Birmingham, Within Grid 3, and Outside of Grid 3 to Total 8-hour Ozone Exceedance Exposure in the Knoxville EAC Area

Aug/Sep (1999), June (2001), and July (2002) Simulation Periods Combined: 2007 Baseline

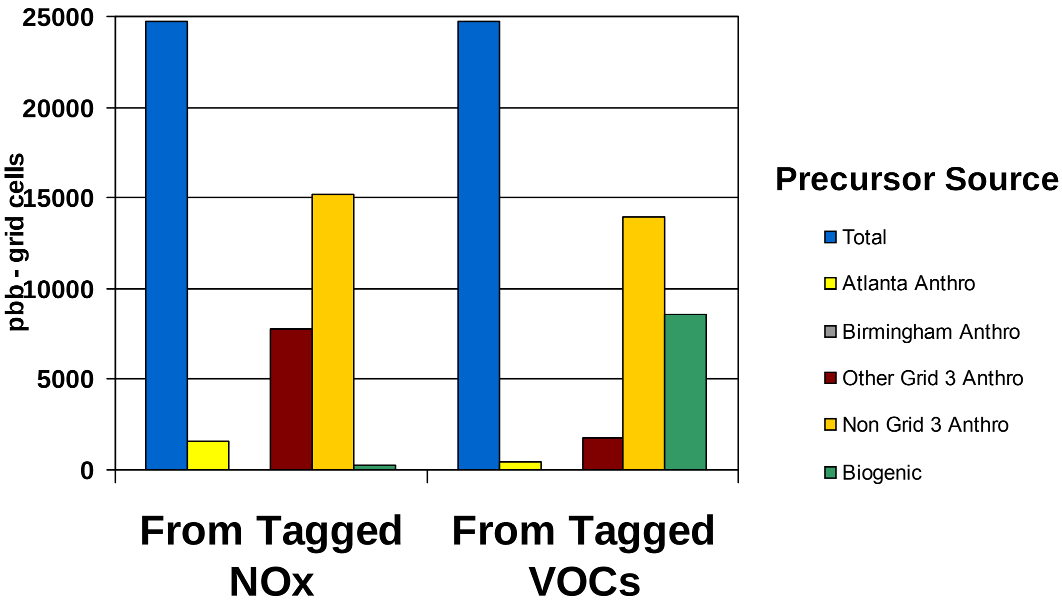


Figure 7-14a.
Total NOx Emissions (tpd) for the EAC Areas for the 2007 Baseline and "All Measures" Strategy Simulation (AS-2)

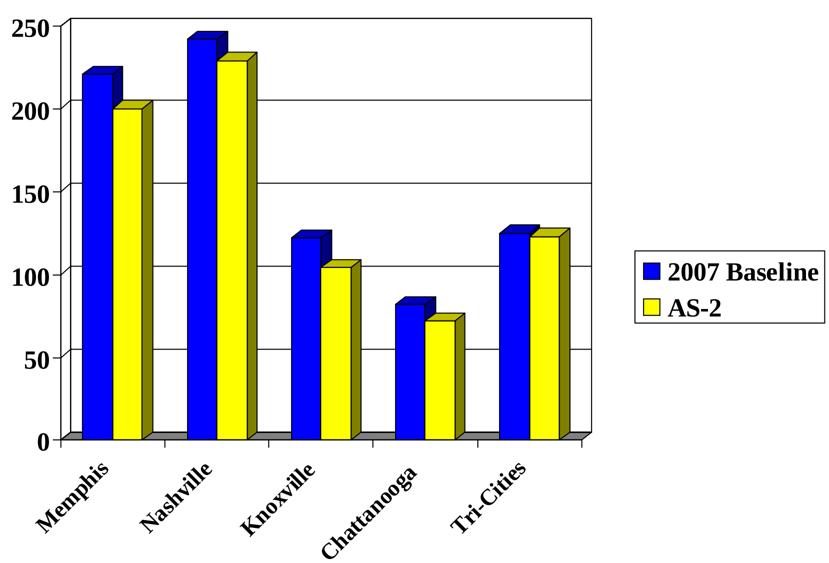
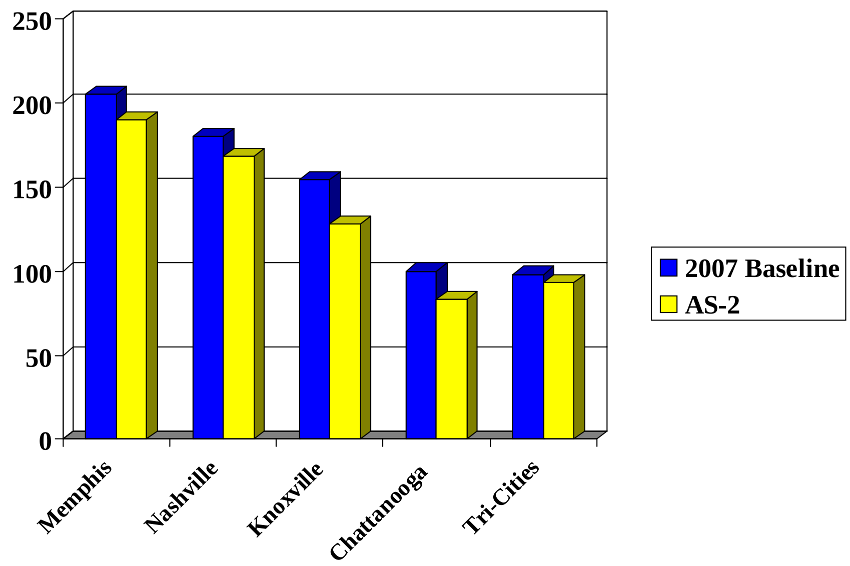


Figure 7-14b.
Total VOC Emissions (tpd) for the EAC Areas for the 2007 Baseline and "All Measures" Strategy Simulation (AS-2)



8. Attainment Demonstration

In this section we present results from the application of the draft EPA 8-hour ozone attainment demonstration procedures. These procedures are outlined in the draft guidance document on using models and other analyses to demonstrate future attainment of the proposed 8-hour ozone standard (EPA, 1999a). They were adapted for the ATMOS modeling domain and simulation periods and applied using the results from the attainment strategy simulation AS-4, as presented in the previous section.

Overview of the ATMOS 8-Hour Ozone Attainment Demonstration Procedures

The draft EPA guidance on 8-hour ozone modeling recommends that an attainment demonstration include three elements: (1) a modeled attainment test, (2) a screening test, and (3) a weight of evidence determination. A brief review of each component and a description of the procedures used for the ATMOS modeling analysis in each phase of the attainment demonstration are provided in this section.

The draft attainment demonstration procedures for 8-hour ozone differ from those for 1-hour ozone. A key difference is that the modeled attainment test is based on relative (rather than absolute) use of the modeling results. Thus, the test relies on the ability of the photochemical modeling system to simulate the change in ozone due to emissions reductions, but not necessarily its ability to simulate exact values for future-year ozone concentrations. Another difference is that the 8-hour attainment test is site-specific while the 1-hour test focuses on an urban-scale modeling domain. Other areas of the domain are considered in the 8-hour analysis as part of a screening test. The modeled attainment and screening tests comprise a part of the "weight of evidence" for the 8-hour ozone attainment demonstration, other factors are also considered as part of the assessment.

Modeled Attainment Test

The modeled attainment test is applied for each monitoring site, and the results for all sites within an area of interest are used to determine whether the test is passed for the area. For a monitoring site to pass the attainment test, the future-year estimated design value for that site must not exceed 84 ppb. Future-year estimated design values (EDVs) are calculated for each site using "current-year" design values and relative reduction factors (RRFs) derived from future-year and current -year modeling results. The current-year design value for a given site is the three-year average of the annual fourth highest measured 8-hour ozone concentration. The RRF is the ratio of the future- to current-year 8-hour simulated maximum ozone concentration in the vicinity of that monitoring site. The EDV is obtained by multiplying the current-year design value by the RRF. The area-wide EDV is the maximum of the site-specific EDVs over all sites in the area.

In applying the modeling attainment test for ATMOS, the attainment test procedures outlined in the draft EPA guidance document were adapted for the ATMOS modeling domain and simulation periods. Key implementation issues are discussed here.

The UAM-V modeling system was run for the three ATMOS simulation periods using current-year (2001) emissions. This ensured the effective and reasonable combination of the results in calculating the RRF and EDV parameters, despite the different base years. In this manner, all three episode periods were put on a consistent basis for use in the attainment test.

An important component of the attainment test is the calculation of a relative reduction factor (RRF) for each site and each simulation day. The RRF represents the ratio of the future-year daily maximum 8-hour ozone concentration to the corresponding base-year value. It is calculated for each site using simulated ozone concentrations within the vicinity of the site. EPA guidance recommends the use of a 15-km radius of influence for determining the maximum 8-hour ozone concentration within the vicinity of a site, and this was used for the ATMOS application. As an alternative to this, we also defined “vicinity” as within one grid cell of the grid cell in which the monitoring site is located. That is, the nine grid cells surrounding a monitoring site were included in the search for the maximum value. For the 4-km grid sites of interest, this resulted in a radius of influence of approximately 6 km.

This alternative radius of influence is smaller than that suggested in the EPA guidance document and it was used in this analysis to examine and quantify the effects of the assumptions inherent in this parameter. The use of a 15-km radius of influence results in an influence zone for many sites that encompasses, or nearly encompasses, other nearby sites that routinely exhibit very different concentration characteristics. The use of a more limited (4-km) radius of influence accommodates the geographic and meteorological variability and the observed concentration gradients. Use of a value smaller than the EPA default value ensures that the sites are considered independently from one another, and preserves the site-specific nature of the attainment-demonstration exercise. In general, we found that the results using a 9-cell radius of influence are in most cases not significantly different than those calculated using the larger radius of influence. Both results are presented in this report.

For ATMOS, the RRF and EDV values were calculated using the ADVISOR database, as presented in Section 7. The ADVISOR database allows the user to specify which simulation days to include in the calculation of the RRF. The user may select the day(s) directly or use one of several day selection options. These include: (1) each simulation day for which the simulated maximum 8-hour ozone value is greater than or equal to a user-specified value (which defaults to the EPA-recommended 70 ppb), (2) all observed 8-hour ozone exceedance days, and (3) all days for which the base-case simulation results are within a user-specified range of model performance. The estimated design value (EDV) for each site is then calculated by multiplying the RRF by the site-specific design value. In the ADVISOR database, there are several options the user may select for the design value. EPA recommends consideration of (1) the design value period, which spans the current year (in this case, 2000-2002), and (2) the period upon which designations are based (in this case, 2001-2003). EPA guidance recommends that the maximum of these two values be used, provided that the value is representative of the meteorological conditions that occur during a typical design value cycle.

For the results presented here, we include all days with simulated current-year 8-hour ozone concentrations greater than or equal to 70 ppb in the primary calculations, and we also consider alternate day selection options. We present results for both the 2000–2002 and 2001-2003 design values, and provide an assessment of design value representativeness.

Screening Test

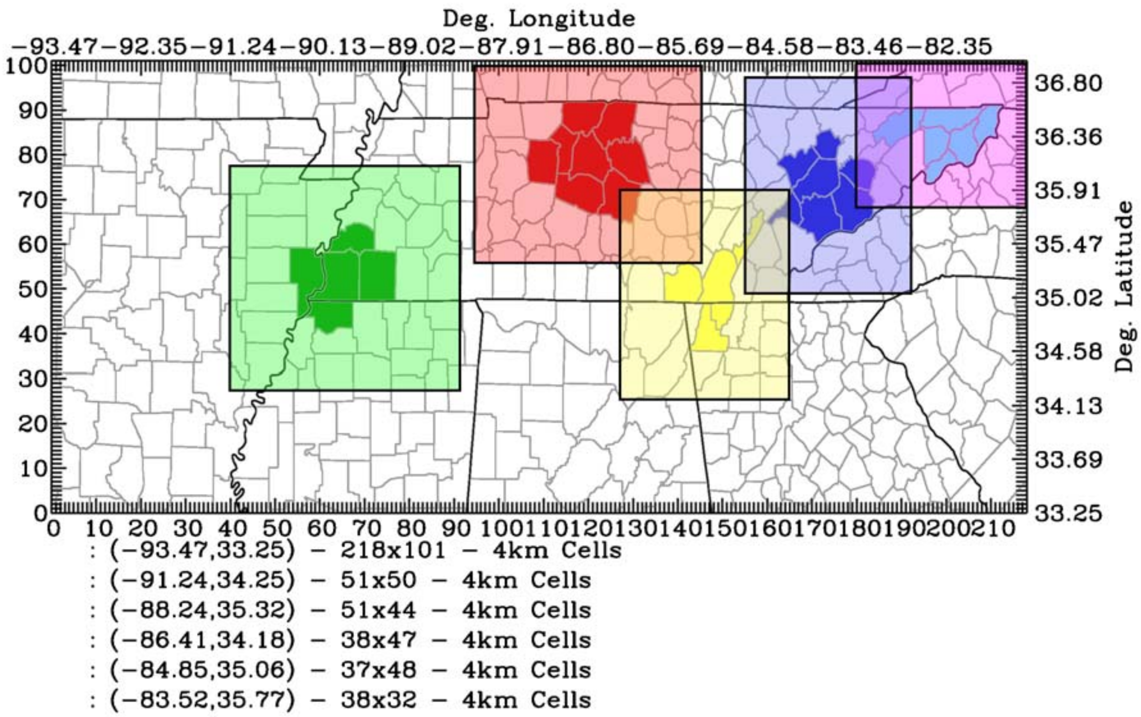
The screening test is intended as an accompaniment to the attainment test and is specifically applied to areas in the domain where the simulated maximum 8-hour ozone concentrations (for the base-case simulation) are consistently greater than any in the vicinity of a monitoring site.

EPA guidance defines “consistently” as 50 percent or more of the simulation days and “greater than” as more than 5 percent higher. Thus, the screening test is designed to be applied to an array of grid cells where the simulated maximum 8-hour ozone concentrations are more than 5 percent higher than any near a monitored location on 50 percent or more of the simulation days. The screening test procedures are otherwise identical to the attainment test procedures; the current-year design value for the unmonitored area is set equal to the maximum value at any site.

We applied the screening test in two ways. First, we considered Grid 3 in its entirety. Since these results do not apply to any one area, they are briefly presented here. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. In the first approach, there are several locations in the southeastern portion of the Grid 3 domain with concentrations that are more than 5 percent greater than the peak vales near any site, but this occurs on only two of the 20 simulation days. Using the 49-cell blocks, one block of cells in the southeastern portion of Grid 3 has simulated concentrations greater than any at any site peak on a total of two out of the 20 simulation days. Again, the "50 percent of days" criteria is not met.

Second, to focus more intensively on the five key areas of interest, we assumed that the extent of the search (for candidate screening test location) should be limited to the region surrounding the EAC area within which emissions from that area could influence the simulated higher ozone concentrations. This same philosophy is typically applied in selecting a photochemical modeling domain for an urban-scale modeling application. Rectangular subregions were specified for each of the EAC areas of interest (these are shown in Figure 8-1). Any screening test locations were labeled “pseudo sites”. Each pseudo site was assigned a design value equal to the maximum design value for any site in the subregion with which it was associated. The screening test was then applied. As noted earlier, from this point on it is the same as the attainment test (as described above). The results of the subregional screening tests for each area are presented later in this section.

Figure 8-1.
Subdomains Used for the Regional Application of the Screening Test for Design Values for ATMOS



Design Value Analysis

The design value is an important part of the modeled attainment test, in which future design values are estimated. For ATMOS, the modeled attainment test primarily uses, as its basis, the observation-based design value for the three-year period spanning the current model year. This value is expected to represent the current period in the same way the modeled simulation periods are expected to represent typical or frequently occurring meteorological conditions. Thus it is important that the base or current design value is representative of typical meteorological conditions. Given the form of the design value metric, however, year-to-year variations in meteorology and especially unusually persistent meteorological conditions during one or more of the years comprising a design value cycle can lead to a design value that is not representative of typical conditions.

As noted earlier in the report, the design value is defined for each monitoring site as the three-year average of the fourth highest 8-hour ozone concentration. This 8-hour ozone NAAQS (in its current form) requires the design value to be less than or equal to 84 parts per billion (ppb). In using the fourth highest ozone concentration and by averaging over a three-year period, the 8-hour ozone design value is formulated in part to accommodate year-to-year variations in meteorological conditions. However, recent variations in the design values for the several of the ATMOS EAC areas have indicated that the metric may not be stable when weather conditions (either ozone conducive or not) persist over the region for large portions of the ozone season. In developing “meteorologically adjusted” design values for each area, our objective was to create a metric similar to the 8-hour design value but less sensitive to yearly meteorological variation. This exercise relies on results of the Classification and Regression Tree (CART) analysis, as discussed in Section 1 of this document.

CART was used in the ATMOS episode selection analysis to classify all ozone season days for the years 1996-2002 according to meteorological and air quality parameters. While the category of a bin reflects the severity of ozone associated with the bin's meteorological conditions, the number of days in a bin represents the frequency with which those conditions occur. Since the bins are determined using a multi-year period, individual years may be normalized such that the different sets of meteorological conditions are represented no more or less than they are on average over all years in the period. This is the basis for our creation of meteorologically adjusted design values.

The methodology described here utilizes the original ATMOS CART analysis for years 1996-2002, and extends the period of consideration to 2003, by applying the same classification rules to 2003 data that were defined in the CART tree. Thus each day between 1996–2003, April to October inclusive, is classified into one of the CART bins. For the design value analysis, we treat the exceedance categories (Categories 3 and 4 bins) as a single category—this does not change the bin structure but broadens the number of days that are considered correctly classified. Finally, we determine design values for the key sites for each EAC area, following the steps outlined below:

Step 1. Determine "key" bins that represent sufficiently frequent conditions

- Key bins are represented in at least four of the eight years by at least one day whose maximum 8-hour ozone value at the site matches the bin category (call these, "site-correct" days).
- Key bins are represented by, on average, at least one day per year, of days whose area-wide maximum 8-hour ozone values match the bin category (call these, "area-correct" days).

Step 2. Determine the number of days to include from each bin.

- For "key" bins, use the rounded average of area-correct bin days per year.
- Include zero days from bins that do not meet the "key" bin requirements.

Step 3. For each year, eliminate non-representative days and excess days from over represented bins.

- Keep only site-correct days.
- For bins with excess days, eliminate days with lower values first.

Step 4. For each year, add days to underrepresented bins.

- Use the average value of site-correct days within that bin, for that year, if available.
- Otherwise, use the average value of site-correct days within that bin for the five-year span centered on that year, if values are available.
- Otherwise, use the average value of site-correct days within that bin for the full eight-year span.

Step 5. Use resulting fourth-highest values from these normalized years to define meteorologically-adjusted design values.

In the course of developing this procedure, we attempted multiple variations of the steps above. Both arbitrary and reasoned decisions led to the methodology presented here, so the remainder of this subsection provides a more detailed discussion of the steps above.

Step 1: Determining Key Bins

This and step 2 appear to have the greatest effect on resulting design values. Certain parameters are arbitrary and were ultimately determined by what led to the most reasonable results. These parameters are the number of years required to have a “site-correct” day, and the minimum average “area-correct” days per year. Since the classification variable from the original ATMOS CART analysis is actually an area-wide 8-hour ozone maximum, the frequency of “area-correct” days seems the most appropriate measure of the prevalence of a particular bin. Therefore the high-ozone bins represent met conditions leading to high ozone somewhere in the area, though not necessarily at the site. On the other hand, the “site-correct” requirement ensures that a high-ozone key bin has representative high values available for a minimum of years, with values for the other years filled in by substitution rules defined at a later step. We wanted the procedure to be inclusive of high ozone bins without resulting in an extreme amount of substitution.

Step 2: Determining Number of Days to Include from Key Bins

Again, we sought a balance between inclusion of high ozone bins for all years, and minimal substitution for the years where a high ozone bin may not appear, or may not appear as frequently as required. Step 2 plays an important role in moderating extremes, since it sets the threshold for the elimination and addition of data in Steps 3 and 4. We decided to use the average from the “area-correct” criteria in step 1, so that the importance attributed to a bin reflects its prevalence in CART as originally intended—representing the area rather than the site. Since the site value is less than the area maximum, use of the “area-correct” day average results in more high ozone bin days than use of a “site-correct” day average. We err on the side of including more high ozone days by rounding rather than truncating the average to an integer. Other ways to determine the day requirement, such as taking the median, may result in either a higher or lower value than the rounded average, so the choice of the rounded average is somewhat arbitrary.

Step 3: Eliminating Days

At this stage and beyond, we consider only days whose maximum 8-hour value at the site is consistent with the category of the bin in which it falls. For high ozone bins, this means we only include days where the high ozone predicted by CART occurs at the site itself.

If a bin has more days per year than the limit set in Step 2, the meteorological conditions are considered over-persistent, and the lowest days are eliminated from consideration until the bin has the desired number of days. By keeping the highest days first, we lean towards a worst-case-scenario. But the eliminated days may also have been among the highest for the year, so this step ultimately has the effect of potentially lowering the fourth highest value and suppressing the effect of over-persistent conditions.

Step 4: Adding Days

This step can increase the fourth highest value by adding high-ozone days that did not appear in the actual year. Thus a bin with fewer days than required is supplemented with days similar to those already in the bin for that year. Adding a day with the average ozone value expands the bin from the middle, preserving the position of the highest and lowest values within the bin, while reducing the lower days' ranking among all days in the year. When a bin is entirely absent from a particular year, the alternative substitution rules are meant to preserve some temporal changes in ozone levels, presumably due to emissions changes. If available, the value for substitution comes from the average over neighboring years, defined as those at most two years before or after the year requiring substitution; these neighboring years are the same whose values are averaged with the middle year in calculating design values. The period-wide average provides a value for substitution only if the five-year substitution rule cannot. Since we use only "site-correct" days for these averages, we guarantee that exceedance values fill open slots in high-ozone bins.

Additional Weight-of-Evidence Analysis

For areas with estimated future-year design values that are less than 90 ppb, additional weigh-of-evidence analyses may be presented to support or enlighten the attainment demonstration. Building directly on the modeling analysis, EPA guidance recommends incorporating key findings from model performance and information on episode representativeness into a weight of evidence analysis. The guidance also recommends the calculation of additional metrics based on modeled outputs that provide a slightly different perspective on the modeling results and specifically the expected ozone reductions. EPA guidance also recommends the examination of air quality and emissions trends, especially if they can be normalized for differences in meteorology. Other types of weight-of-evidence or corroborative analyses discussed in the EPA guidance include the use of observational models, uncertainty analysis, examination of design value representativeness, and use of alternative applications (for example, including/excluding days) in the attainment test calculations.

For ATMOS, we offer a variety of weight-of-evidence analyses that are designed to improve our understanding and interpretation of the modeled attainment test results, and to explore the effects of the various assumptions that are employed in the application of the photochemical model and the attainment test procedures. Our goal here is to make the best possible use of the modeling results and the observed data to assign a level of confidence to the outcome of the modeled attainment test. The weight-of-evidence analyses for each area are tailored to the observed data; the meteorological, geographical, and monitoring network considerations; and the modeling results for the area.

Attainment Demonstration for the Memphis EAC Area

The attainment demonstration analysis for the Memphis EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Memphis EAC area includes Shelby, Fayette, and Tipton Counties in Tennessee, Crittenden County in Arkansas, and DeSoto County in Mississippi. There are four monitoring sites in the Memphis EAC area, two in Shelby County (Edmund Orgill Park and Frayser), one in Crittenden County (Marion), and one in DeSoto County.

Modeled Attainment Test for Memphis

The modeled attainment test was applied for all sites in the Memphis EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used also both the 2000-2002 and the 2001-2003 design values for each site. Table 8-1 lists the observation-based design values (DV) and future-year 2007 estimated design values (EDV) for the AS-4 control-measures simulation for each site in the Memphis EAC area.

Table 8-1.
Observed and Estimated Design Values (ppb) for Sites in the Memphis EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000–2002 and 2001–2003 Design Values

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Edmund Orgill Park	90	82	83	89	81	82
Frayser	87	82	82	84	79	79
Marion	94	88	88	92	86	86
DeSoto Co.	86	80	81	81	75	76

The maximum observation-based design value for the 2000–2002 period is 94 ppb, for the Marion monitoring site in Crittenden County, AR. The corresponding maximum future-year (2007) EDV for the area is also calculated for the Marion monitoring site. The future-year EDV for this site is 88 ppb using the 15-km radius of influence, and 88 ppb using the 9-cell radius of influence. The details of the calculations for the 15-km approach are provided in Table 8-2, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for all other sites in the area (including the Edmund Orgill Park and Frayser sites in Shelby County, TN and the DeSoto County site in MS) are below 84 ppb. The values with the 15-km approach are 82 ppb for Edmund Orgill Park, 82 ppb for Frayser, and 80 ppb for DeSoto County. The values are the same for Frayser and one ppb higher for the other two sites for the 9-cell approach.

Table 8-2.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Marion, AR Site in the Memphis EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	90.5	87.1
9/1/99	78.2	78.2
9/2/99	104.9	99.5
9/3/99.	119.9	109.5
9/4/99	73.2	68.4
9/7/99	74.5	72.4
6/18/01	101.0	94.9
6/19/01	88.1	82.3
6/20/01	103.0	97.2
6/22/01	77.4	71.4
7/6/02	100.0	89.1
7/7/02	88.6	83.6
7/8/02	118.9	111.2
7/9/02	79.8	72.4
7/10/02	70.9	68.4
Average	91.3	85.7
EDV Calculations		
RRF		0.94
2000-2002 DV		94
2007 EDV (2002)		88
2001-2003 DV		92
2007 EDV (2003)		86

The design values for 2001-2003 are slightly lower than those for 2000-2002 at all sites, with a maximum value of 92 ppb for the Marion site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 86 ppb (for the Marion site) and values of 81, 79, and 75 ppb, respectively, for the Edmund Orgill Park, Frayser, and DeSoto County sites.

Limiting or otherwise selecting the days based on observed exceedances or model performance does not change the resulting EDV for the Marion site. This is because model performance is acceptable for most days and all high ozone days.

Thus, the attainment test for the Memphis EAC area is nearly passed for the AS-4 2007 control measure scenario, with a range in maximum area-wide EDV of 86 to 88 ppb, depending upon the assumptions employed in the application of the attainment test. Of the four monitoring sites located in the area, the EDV is above 84 ppb for only one of the sites.

Regional Screening Test for Memphis

The screening test was applied for the Memphis-area subregion defined in Figure 8-1. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for four and six days, respectively, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analyses

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Memphis EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-3 summarizes the percent change in each of these metrics for the Memphis EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-3.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Memphis EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	59
Number of grid-cell hours > 84 ppb	48
Number of grid cells with 8-hour max > 84 ppb	46
Total 1-hour ozone > 84 ppb	54

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 50 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the hourly and 8-hour ozone values from the current-year simulation.

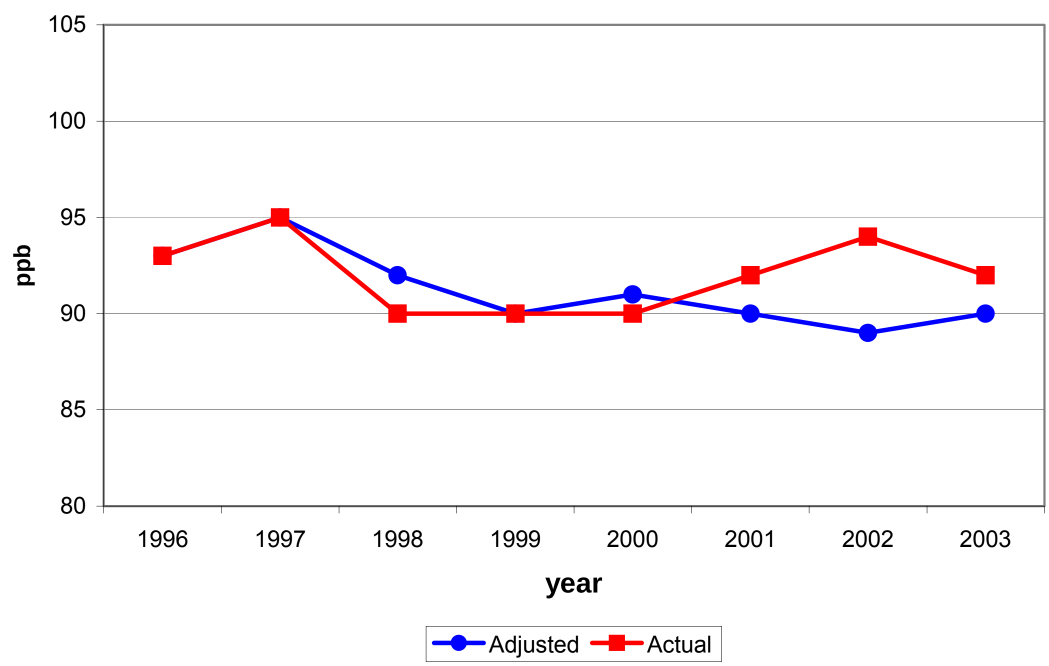
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Memphis area, based on the Marion site, are listed in Table 8-4 and plotted in Figure 8-2.

Table 8-4.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Marion

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• DVs	93	95	90	90	90	92	94	92
• 4th highest	96	91	85	95	91	92	100	84
Adjusted								
• - DVs	93	95	92	90	91	90	89	90
• - 4th highest	98	88	92	91	91	89	89	92

Figure 8-2.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Marion

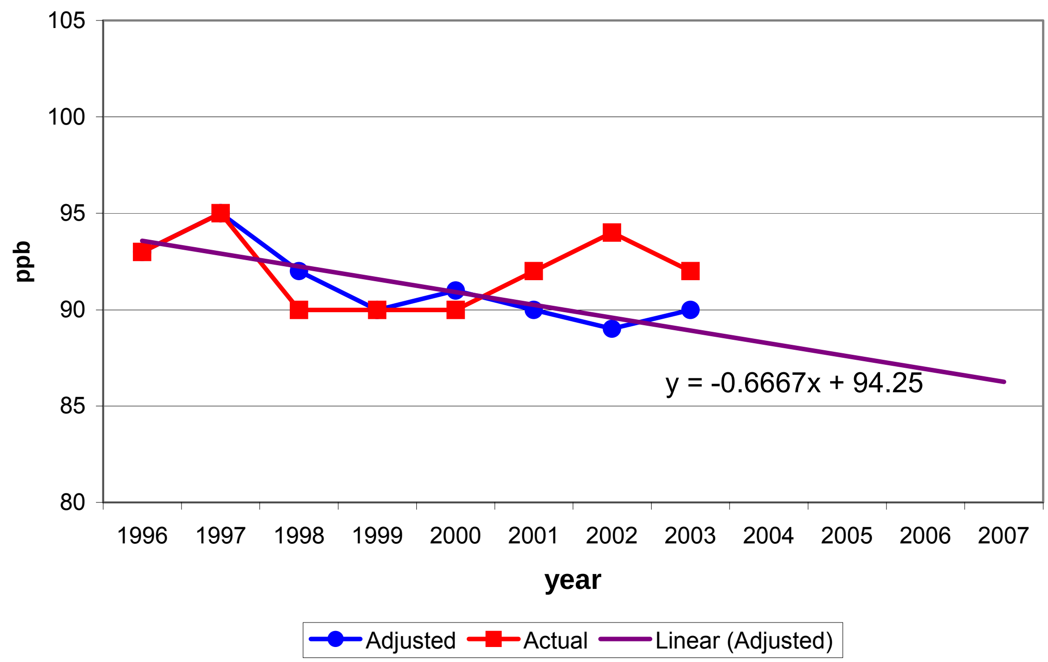


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 91 ppb, only one ppb lower than the average actual design values. But, as intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is much more stable than the observation-based design value. Using this methodology, the high design value for 2002 is attributable to more persistent than usual ozone conducive meteorological conditions. Unfortunately, this is the primary value used in the ATMOS modeling analysis as the basis of the modeled attainment. These results indicate that a more appropriate design value for application of the attainment test is approximately 90 ppb. Use of a value of 90 ppb in the attainment test results in a 2007 EDV of 84 ppb.

The observation that meteorologically-adjusted design values change more gradually and linearly than actual design values, invites one to extrapolate to future years. Figure 8-3 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 86 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint is likely to represent a high-end value. It is expected that the ATMOS modeling results, which take into account the expected future emissions reductions, using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-3.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically-Adjusted 8-Hour Ozone Trends for Marion



Summary Attainment Demonstration for Memphis

The attainment and screening tests and additional corroborative analyses indicate that the Memphis EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the results of the modeled attainment test significantly. There are no locations within a subdomain encompassing the Memphis EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 50 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

Three of the four monitoring sites in the Memphis area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. One site, the Marion site in Crittenden County, AR, has an EDV that is greater than the 84 ppb standard. The 2007 EDV for this site is 88 ppb if the 2000-2002 design value is used, 86 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. The 2000-2002 design value is the highest recorded in recent years. Based on the values for the other years as well as the indications from the meteorological adjustment, use of the 2000-2002 design value likely represents a worst case for Memphis for 2007.

To further support future attainment of the 8-hour ozone standard for the Memphis area, ADEQ is currently designing a scoping study and field program to examine the spatial representativeness and causes of high observed ozone concentrations at the Marion site. An improved understanding of the 8-hour ozone issues in Crittenden County will enable the more effective implementation of the planned attainment/maintenance strategies for the area.

Attainment Demonstration for the Nashville EAC Area

The attainment demonstration analysis for the Nashville EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Nashville EAC area includes Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties. There are eight monitoring sites in the Nashville EAC area.

Modeled Attainment Test for Nashville

The modeled attainment test was applied for all sites in the Nashville EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used also both the 2000-2002 and the 2001-2003 design values for each site. Table 8-5 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Nashville EAC area.

Table 8-5.
Observed and Estimated Design Values (ppb) for Sites in the Nashville EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
E. Nashville Health Center	71	66	67	71	66	67
Percy Priest Dam	80	75	73	77	72	71
Rutherford Co.	84	77	76	80	73	72
Rockland Road.	88	81	82	86	79	80
Wright's Farm	87	82	80	82	77	76
Fairview	87	80	79	84	77	76
Lebanon	85	76	76	82	74	73
Dickson Co.	NA	NA	NA	NA	NA	NA

The maximum observation-based design value for the 2000-2002 period is 88 ppb, for the Rockland Road monitoring site. Two sites have values of 87 ppb. These are Cottontown Wrights Farm and Fairview. The corresponding maximum future-year (2007) EDV for the area is calculated for the Wright's Farm site if the 15-km radius of influence is used and for the Rockland Road site if the 9-cell radius of influence is used. In both cases, the value is 82 ppb. The details of the calculations for the Rockland Road site are provided in Table 8-6, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for all other sites in the Nashville EAC area are at or below 80 ppb (well below 84 ppb).

Table 8-6.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Rockland Rd. Site in the Nashville EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	89.6	86.4
9/1/99	107.9	99.7
9/2/99	74.9	72.6
9/3/99.	91.8	86.6
9/4/99	131.3	122.7
9/5/99	84.7	80.3
9/6/99	86.7	82.3
9/7/99	76.9	74.4
9/8/99	88.9	85.8
6/18/01	89.7	82.0
6/19/01	99.5	89.0
6/20/01	116.0	109.9
6/21/01	75.0	69.9
6/22/01	76.9	70.5
7/6/02	72.2	68.4
7/7/02	74.8	71.3
7/8/02	85.1	78.3
7/9/02	94.7	90.4
7/10/02	112.7	84.6
Average	91.0	84.5
EDV Calculations		
RRF		0.93
2000-2002 DV		88
2007 EDV (2002)		81
2001-2003 DV		86
2007 EDV (2003)		79

The design values for 2001-2003 are lower than those for 2000-2002 at most sites, with a maximum value of 86 ppb for the Rockland Road site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 79 ppb (for the Rockland Road site).

Using only observed exceedance days in the calculation results in an EDV of 83 ppb for the Rockland Road site (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance for that site gives an EDV of 82 ppb (compared to 81 ppb with all other parameters kept the same). Thus, the calculation of the EDV is somewhat sensitive to the selection of days.

The attainment test for the Nashville EAC area is passed for the AS-4 2007 control-measure scenario, with a range in maximum area-wide EDV of 79 to 83 ppb, depending upon the assumptions employed in the application of the attainment test.

Regional Screening Test for Nashville

The screening test was applied for the Nashville-area subregion defined in Figure 8-3. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-

cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for three days using both approaches, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To support the finding of modeled attainment for the Nashville area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Nashville EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-7 summarizes the percent change in each of these metrics for the Nashville EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-7.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Nashville EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	70
Number of grid-cell hours > 84 ppb	55
Number of grid cells with 8-hour max > 84 ppb	60
Total 1-hour ozone > 84 ppb	63

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 60 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

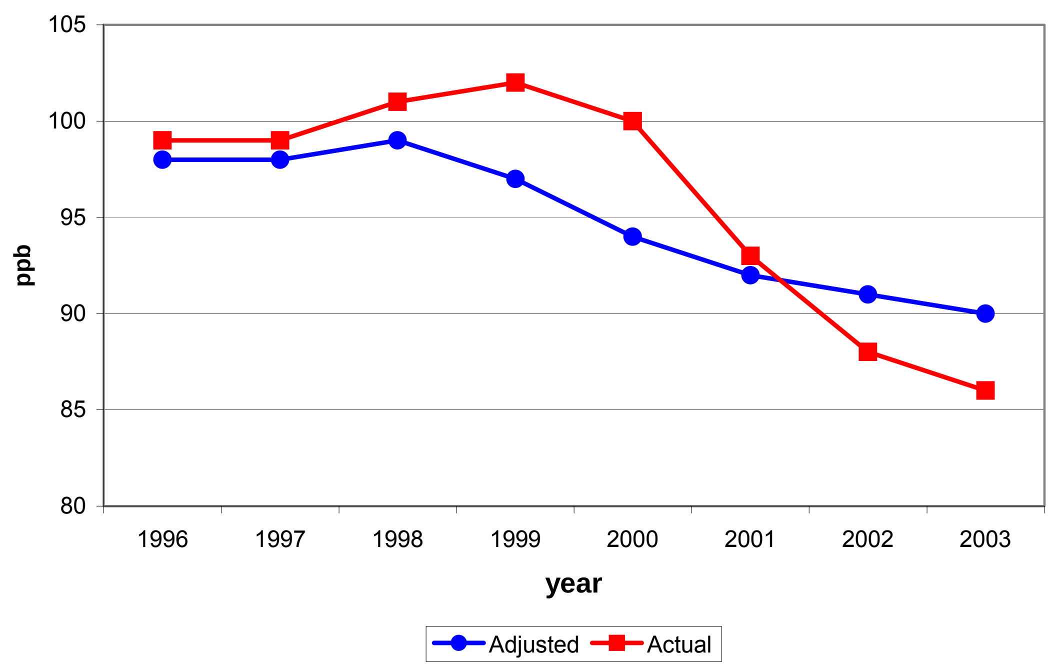
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Nashville area, based on the Rockland Road site, are listed in Table 8-8 and plotted in Figure 8-4.

Table 8-8.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Rockland Road

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	99	99	101	102	100	93	88	86
• - 4th highest	97	100	107	101	93	86	86	86
Adjusted								
• - DVs	98	98	99	97	94	92	91	90
• - 4th highest	95	101	101	91	92	94	87	90

Figure 8-4.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Rockland Road

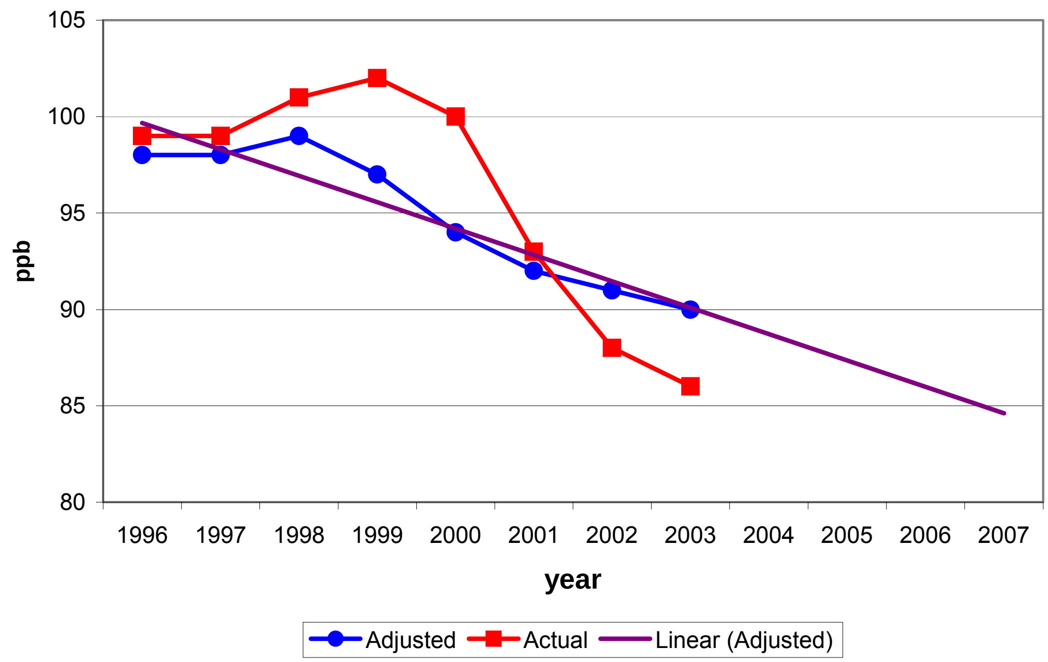


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 94 ppb, two ppb lower than the average actual design value of 96 ppb. But, as intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is more stable than the observation-based design value, although both show a clear tendency toward lower design values between 1998/1999 and 2003. The results also indicate that the design value for 2000-2002, as used in the modeled attainment may be low as a result of fewer days than normal with ozone-conducive meteorological conditions during 2002. These results suggest that a more appropriate design value for application of the attainment test is approximately 90 ppb. Use of a value of 90 ppb in the attainment test results in a 2007 EDV of 83 ppb, whereas use of a value of 91 ppb gives a result of 84 ppb for the EDV. In either case, the attainment test is still passed. This finding adds to the robustness of the analysis, in that even if the design value used for the attainment test was lower than might be expected under more typical meteorological conditions, the test would still be passed.

Figure 8-5 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 84 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst-case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-5.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Rockland Road



Summary Attainment Demonstration for Nashville

The attainment and screening tests and additional corroborative analyses indicate that the Nashville EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test. There are no locations within a subdomain encompassing the Nashville EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the

2007 AS-4 control measures simulation - approximately 60 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

All of the monitoring sites in the Nashville area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. The areawide 2007 EDV for this site is 82 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. Use of a meteorologically adjusted DV that is higher than observed supports a finding of modeled attainment.

Attainment Demonstration for the Knoxville EAC Area

The attainment demonstration analysis for the Knoxville EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Knoxville EAC area includes Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties. There are eight monitoring sites in the Knoxville EAC area. Four of these sites are located in the greater Knoxville area, while four others are located in the Great Smoky Mountains National Park.

Modeled Attainment Test for Knoxville

The modeled attainment test was applied for all sites in the Knoxville EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-9 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Knoxville EAC area.

Table 8-9.
Observed and Estimated Design Values (ppb) for Sites in the Knoxville EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
East Knoxville	92	85	84	88	81	81
Spring Hill	96	90	89	92	86	86
Jefferson Co.	95	87	86	91	83	83
Anderson Co.	92	83	85	87	79	80
Cove Mountain	96	86	86	92	83	82
Clingman's Dome	98	89	87	92	83	82
Cades Cove	79	70	70	76	68	68
Look Rock	94	84	84	93	83	84

The maximum observation-based design value for the 2000-2002 period is 98 ppb, for the Clingman's Dome monitoring site. Among the non-GSM sites, The Spring Hill site has the highest value of 96 ppb. The corresponding maximum future-year (2007) EDVs for these sites are 89 and 90 ppb, respectively, if the 15-km radius of influence is used, and 87 and 89 ppb, respectively, if the 9-cell radius of influence is used. The details of the calculations for the Spring Hill site are provided in Table 8-10, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for four other sites are also above 84 ppb, these are East Knoxville (using the 15-km approach only), Jefferson Co., Anderson Co. (using the 9-cell approach only), and Cove Mountain. The EDVs for the remaining two GSM sites are at or below 84 ppb.

Table 8-10.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Spring Hill Site in the Knoxville EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	77.5	76.9
9/1/99	76.3	73.9
9/2/99	91.3	87.6
9/3/99.	89.4	89.9
9/4/99	92.1	85.9
9/6/99	70.6	66.7
9/7/99	84.9	79.6
9/8/99	89.5	86.5
6/18/01	81.6	81.9
6/19/01	102.0	89.8
6/20/01	111	99.3
6/21/01	92.7	85.5
7/6/02	82.4	76.0
7/7/02	98.4	90.1
7/8/02	73.7	70.0
7/9/02	110.5	98.8
7/10/02	80.5	74.8
Average	88.9	83.2
EDV Calculations		
RRF		0.94
2000-2002 DV		96
2007 EDV (2002)		90
2001-2003 DV		92
2007 EDV (2003)		86

The design values for 2001-2003 are lower than those for 2000-2002 for all sites, with a maximum value of 93 ppb for the Look Rock monitoring site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 86 ppb, in this case for the Spring Hill site. Using the 2001-2003 values, the EDVs for all other sites in the Knoxville area are at or below 84 ppb.

Using only observed exceedance days in the calculation reduces the number of days available to the calculation but the resulting EDV is unchanged (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance for that site gives an EDV of 91 ppb (compared to 90 ppb with all other parameters kept the same). Thus, the calculation of the EDV is somewhat sensitive to the selection of days.

The attainment test for the Knoxville EAC area is not passed for the AS-4 2007 control-measure scenario, with a range in maximum area-wide EDV of 86 to 90 ppb, depending upon the assumptions employed in the application of the attainment test.

Regional Screening Test for Knoxville

The screening test was applied for the Knoxville-area subregion defined in Figure 8-5. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for three days using the 15-km approach and for two days using the 9-cell approach, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To further examine the modeling results and the findings from the application of the modeled attainment test for the Knoxville area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Knoxville EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-11 summarizes the percent change in each of these metrics for the Knoxville EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-11.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Knoxville EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	85
Number of grid-cell hours > 84 ppb	59
Number of grid cells with 8-hour max > 84 ppb	66
Total 1-hour ozone > 84 ppb	76

The number of grid cells with hourly or 8-hour ozone concentrations greater than 84 ppb is reduced by about 60 percent. The amount of ozone greater than this value is reduced by an even greater percentage (about 80 percent). These metrics indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

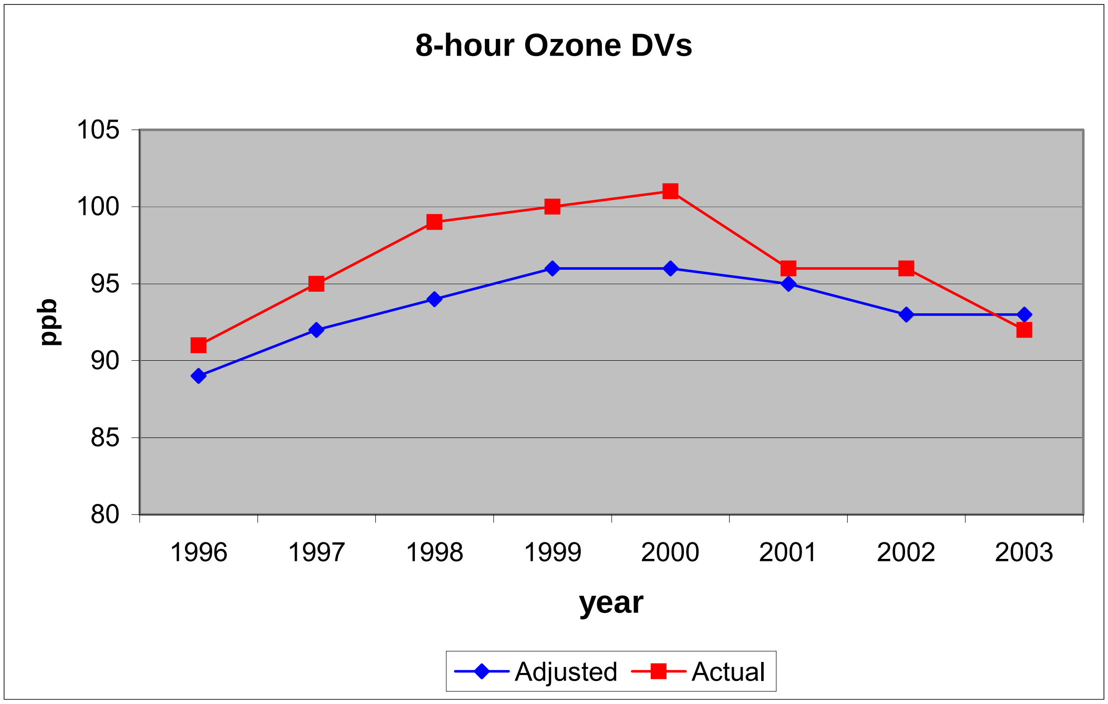
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Knoxville area, based on the Spring Hill site, are listed in Table 8-12 and plotted in Figure 8-6.

Table 8-12.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Spring Hill

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	91	95	99	100	101	96	96	92
• - 4th highest	98	96	95	99	100	90	98	90
Adjusted								
• - DVs	89	92	94	96	96	95	93	93
• - 4th highest	92	93	97	100	92	93	96	91

Figure 8-6.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Spring Hill

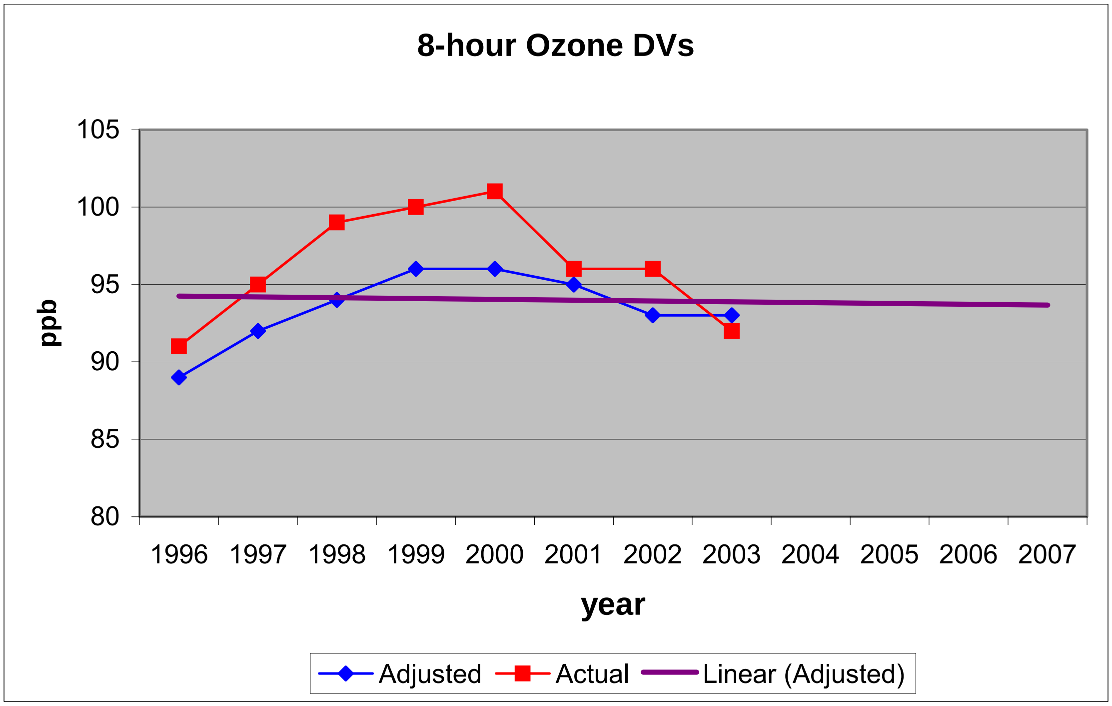


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 93 ppb, three ppb lower than the average actual design value of 96 ppb. As intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is more stable than the observation-based design value, although both show a clear tendency toward increasing DV from 1996 to 2000 and the reverse tendency between 2000 and 2003. The results also indicate that the design value for 2000-2002, as used in the modeled attainment, may be higher than expected for meteorologically typical design value period. The results suggest that a more appropriate design value for application of the attainment test is approximately 93 ppb. Use of a value of 93 ppb in the attainment test results in a 2007 EDV of 87 ppb, which brings the area closer to the passing the modeled attainment test. Nevertheless, this result suggests that additional emissions reductions will be needed to bring Knoxville into attainment by 2007.

Figure 8-7 below shows the trend in adjusted design values out to 2007. Linear extrapolation is not well suited to the changing design values, so we anchored the trend line at 1998 in this example. The 2007 extrapolated value is still greater than 90 ppb, as this assumes that the changes in emissions for 2003 to 2007 will follow the trends of 1998 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-7.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Spring Hill



Summary Attainment Demonstration for Knoxville

The modeled attainment test indicates that the Knoxville EAC area will likely not achieve attainment of the 8-hour ozone standard by 2007, unless additional controls to those included in the AS-4 control measure package are implemented. The modeling and attainment test results suggest a range in future-year estimated design values from 86 to 90 ppb. The higher value corresponds to the use of the 2000-2002 design value in the calculations, and the lower value corresponds to the use of the 2001-2003 DV. Although the EDV values are relatively high, the values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 60 to 80 percent for the various exposure metrics.

The difference in results using the different design values prompted an examination of the representativeness of the design value. A meteorologically adjusted design value for 2002 was calculated and use of this value gives a future EDV of 87 ppb. Thus, use of a meteorologically adjusted DV is consistent with the use of the 2001-2003 value.

The oxidant tagging results (as presented in Section 7 of this document) indicate that 8-hour ozone concentrations in the Knoxville area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia) will contribute positively to lower ozone in the Knoxville region.

Attainment Demonstration for the Chattanooga EAC Area

The attainment demonstration analysis for the Chattanooga EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Chattanooga EAC area includes Hamilton, Marion and Meigs Counties in Tennessee, and Walker and Catoosa Counties in Georgia. There are three monitoring sites in the Chattanooga EAC area.

Modeled Attainment Test for Chattanooga

The modeled attainment test was applied for all sites in the Chattanooga EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-13 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Chattanooga EAC area.

Table 8-13.
Observed and Estimated Design Values (ppb) for Sites in the Chattanooga EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Sequoyah	93	85	85	87	79	80
Chattanooga VAAP	92	84	85	88	80	81
Meigs Co.	93	85	85	88	81	80

The maximum observation-based design value for the 2000-2002 period is 93 ppb, for both the Sequoyah and Meigs Co. monitoring sites. The value for the VAAP site is also very similar. The corresponding maximum future-year (2007) EDV for the area is 85 ppb (again both for the Sequoyah and Meigs Co. sites). The result is the same using both the 15-km radius of influence as well as the 9-cell radius of influence. The details of the calculations for the Sequoyah site are provided in Table 8-14, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV.

Table 8-14.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Sequoyah Site in the Chattanooga EAC Area

The concentrations and RRF Values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	95.4	89.0
9/1/99	83.0	76.7
9/2/99	97.2	90.0
9/3/99.	111.9	103.3
9/4/99	128.0	116.4
9/5/99	72.9	67.1
9/7/99	90.7	84.4
9/8/99	93.5	90.0
6/18/01	83.5	80.0
6/19/01	105.0	92.8
6/20/01	130.0	123.8
6/21/01	97.2	88.6
7/6/02	91.6	83.4
7/7/02	100.7	90.9
7/8/02	105.5	88.9
7/9/02	96.2	88.3
7/10/02	89.9	83.3
Average	98.4	90.4
EDV Calculations		
RRF		0.92
2000-2002 DV		93
2007 EDV (2002)		85
2001-2003 DV		87
2007 EDV (2003)		79

The design values for 2001-2003 are lower than those for 2000-2002 at all three sites, with a maximum value of 88 ppb for the VAAP and Meigs Co. sites. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 81 ppb (for the Meigs Co. site).

Using only observed exceedance days in the calculation results in an EDV of 84 ppb for the Sequoyah site (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance does not change the EDV, since model performance is generally very good for the Chattanooga sites.

The attainment test for the Chattanooga EAC area is nearly passed for the AS-4 2007 control-measure scenario, with a maximum area-wide EDV of 85.

Regional Screening Test for Chattanooga

The screening test was applied for the Chattanooga-area subregion defined in Figure 8-7. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for four days using the 15-km approach and for 11 days using the 9-cell approach. This outcome resulted in a candidate screening test location for the Chattanooga area, located northeast of the Chattanooga urban area. Application of the attainment test procedures for this location using a design value of 93 ppb (the maximum for any site within the subregion) gives an EDV of 84 ppb, so the screening test is passed.

Additional Corroborative Analysis

To support a finding of attainment for the Chattanooga area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Chattanooga EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-15 summarizes the percent change in each of these metrics for the Chattanooga EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-15.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Chattanooga EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	75
Number of grid-cell hours > 84 ppb	60
Number of grid cells with 8-hour max > 84 ppb	64
Total 1-hour ozone > 84 ppb	70

The number of grid cells with hourly or 8-hour ozone concentrations greater than 84 ppb is reduced by about 60 percent. The amount of ozone greater than this value is reduced by an even greater percentage (about 70-75 percent). These metrics indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

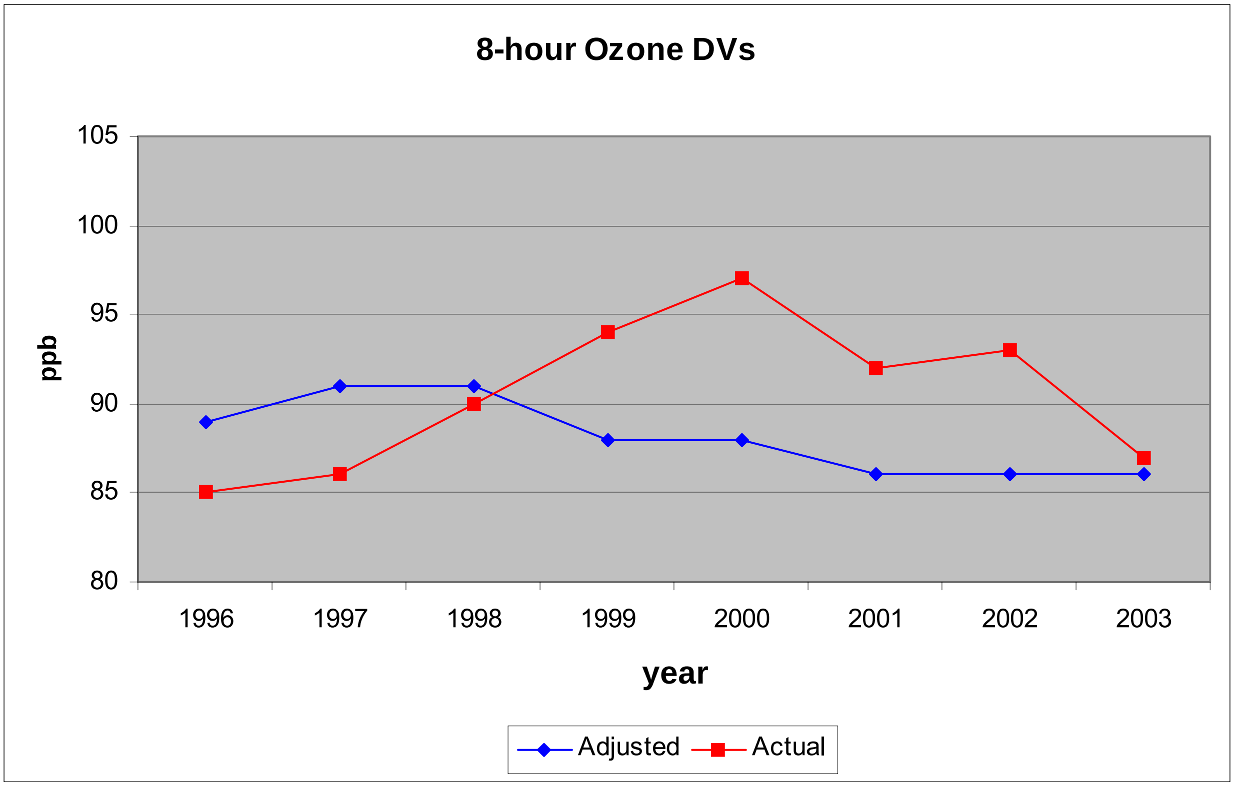
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Chattanooga area, based on the Sequoyah site, are listed in Table 8-16 and plotted in Figure 8-8.

Table 8-16.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Sequoyah

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	85	86	90	94	97	92	93	87
• - 4th highest	85	89	97	98	98	82	99	80
Adjusted								
• - DVs	89	91	91	88	88	86	86	86
• - 4th highest	98	89	88	87	89	82	89	89

Figure 8-8.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Sequoyah

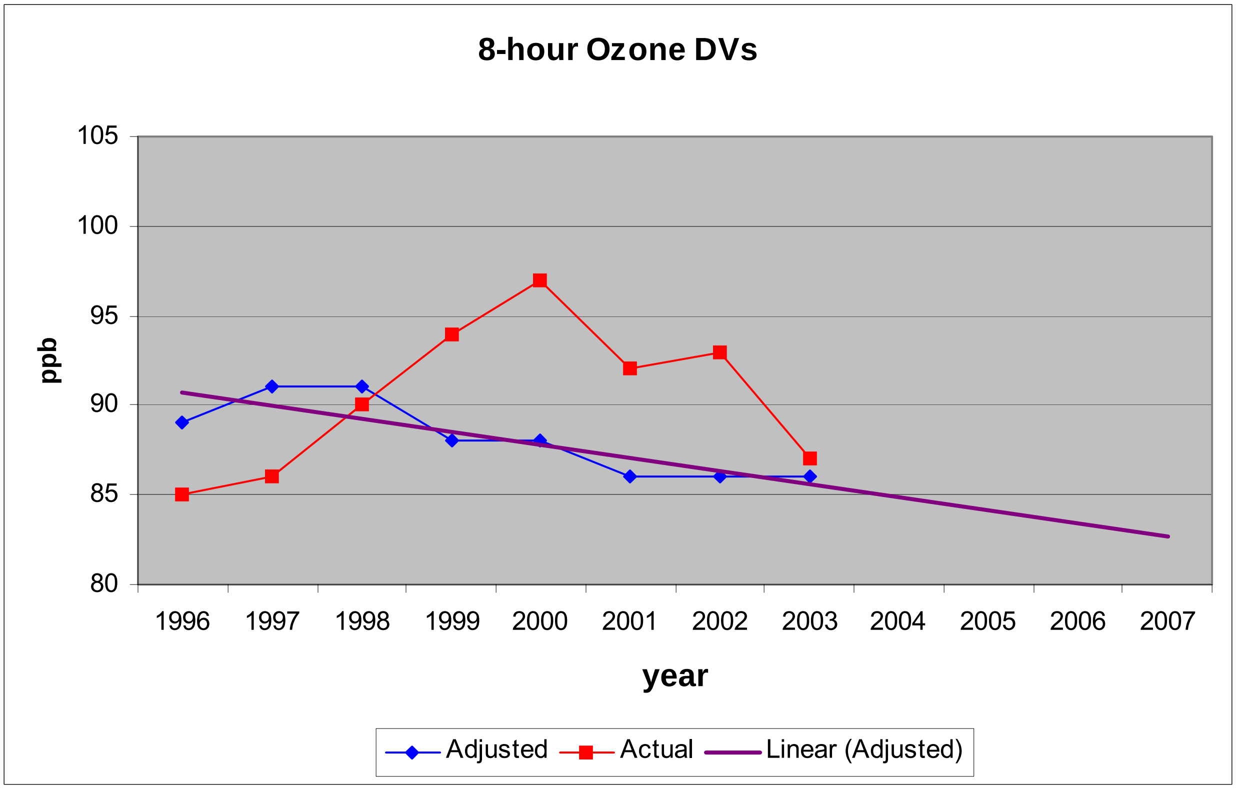


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 88 ppb, two ppb lower than the average actual design value of 90 ppb. The adjusted design values exhibit less variation between years.

The higher design value for 1999, 2000, and for 2002 resulted from a greater number of a certain type of ozone conducive meteorological conditions during those summers, coupled with the fact that this occurred for two or more of the years included in the DV cycle. Conditions associated with the four highest ozone days for 1998 and 2003 were more typical of frequently occurring conditions. The results suggest that the 2000-2002 DV of 93 ppb is representative of a period that had more frequent than usual ozone conducive conditions and that the 2001-2003 value (86 ppb) is a more representative DV. Use of a value of 86 ppb in the attainment test results in a 2007 EDV of 79 ppb. These results suggest that more weight should be given to the attainment test results using the 2001-2003 DV, than to the results using the 2000-2002 DV and support a finding of modeled attainment

Figure 8-9 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 83 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-9.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Sequoyah



Summary Attainment Demonstration for Chattanooga

The attainment and screening tests and additional corroborative analyses indicate that the Chattanooga EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test, but do suggest an even greater response for higher ozone days than when all days are considered. There is one location within a subdomain encompassing the Chattanooga EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. When the attainment test is applied for this location using the maximum design value for any site in the subregion, it is passed. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 60 to 75 percent for each of the exposure metrics. The amount of excess ozone is reduced by a somewhat greater percentage than the incidence (number of hours) of high ozone.

Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation—that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values. In addition, the oxidant tagging results (as presented in Section 7 of this document) indicate that 8-hour ozone concentrations in the Chattanooga area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia) will contribute positively to lower ozone in the Chattanooga region.

All three of the monitoring sites in the Chattanooga area have future-year estimated design values for 8-hour ozone that are less than or equal to 85 ppb if the 2000-2002 design value is used and less than or equal to 81 ppb if the 2001-2003 design value is used. Analysis of the effects of meteorology on the design value provides an estimate of a meteorologically adjusted design value for both 2000-2002 and 2001-2003 that is equal to 86 ppb. Use of a meteorologically adjusted DV of 86 ppb is consistent with the outcome of the attainment test based on the use of the 2001-2003 DV and gives an EDV of 79 ppb. Meteorologically adjusted trends indicate a value of 83 ppb, assuming that the emissions changes between 2003 and 2007 will be, on average, the same as that for 1996-2003.

Regional- and national-scale modeling by the Georgia Department of Natural Resources, Environmental Protection Division (GEPD) and the U.S. EPA, gives even lower future-year EDVS for the Chattanooga area. The GEPD EDV for 2007 for Chattanooga is 81 ppb, while that for the Clear Skies Initiative is 79 ppb. These other studies use coarser grid resolution, but may be more specific in incorporating regional (e.g., for Atlanta) and national measures. Therefore, these results further support a finding of attainment.

Finally, it is important to note that the future-year emissions estimates for Chattanooga do not fully reflect the reduced number of permitted non-major industrial sources (approximately 12 percent) and the loss in manufacturing jobs (approximately 13 percent) that has occurred in the Chattanooga area during the past several years (1999-2002). Overall, these factors would tend to lower the future-year emissions and further support a finding of attainment.

Attainment Demonstration for the Tri-Cities EAC Area

The attainment demonstration analysis for the Tri-Cities EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Tri-Cities EAC area includes Carter, Hawkins, Sullivan, Unicoi, and Washington Counties. There are two monitoring sites in the Tri-Cities EAC area.

Modeled Attainment Test for Tri-Cities

The modeled attainment test was applied for all sites in the Tri-Cities EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-17 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for the two sites in the Tri-Cities EAC area.

Table 8-17.
Observed and Estimated Design Values (ppb) for Sites in the Tri-Cities EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Kingsport	92	84	84	86	79	78
Blountville	90	83	83	86	80	79

The maximum observation-based design value for the 2000-2002 period is 92 ppb, for the Kingsport monitoring site. The corresponding maximum future-year (2007) EDV for the area is 84 ppb, regardless of the approach used in defining the vicinity of the site. The details of the calculations for the Kingsport site are provided in Table 8-18, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV.

Table 8-18.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Kingsport Site in the Tri-Cities EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
9/1/99	73.1	66.2
9/2/99	74.3	66.2
9/3/99.	72.8	69.0
9/4/99	70.7	66.3
9/7/99	72.4	70.1
9/8/99	82.7	76.7
6/18/01	75.7	71.4
6/19/01	98.5	93.4
6/20/01	79.6	77.1
6/21/01	97.8	92.7
6/22/01	74.2	69.2
7/6/02	82.1	69.1
7/7/02	84.7	76.6
7/8/02	87.3	83.2
7/9/02	114.8	98.8
Average	82.7	76.4
EDV Calculations		
RRF		0.92
2000-2002 DV		92
2007 EDV (2002)		84
2001-2003 DV		86
2007 EDV (2003)		80

The design values for 2001-2003 are lower than those for 2000-2002, with a value of 86 ppb for both sites. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 79 ppb for the Kingsport site and a value of 80 ppb for the Blountville (Sullivan Co.) site.

The attainment test for the Tri-Cities EAC area is passed for the AS-4 2007 control-measure scenario, with a value of 84 ppb for the maximum area-wide EDV.

Regional Screening Test for Tri-Cities

The screening test was applied for the Tri-Cities-area subregion defined in Figure 8-9. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for eight days using both approaches, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To support the finding of modeled attainment for the Tri-Cities area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Tri-Cities EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-19 summarizes the percent change in each of these metrics for the Tri-Cities EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-19.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Tri-Cities EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	73
Number of grid-cell hours > 84 ppb	55
Number of grid cells with 8-hour max > 84 ppb	52
Total 1-hour ozone > 84 ppb	69

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 50-70 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

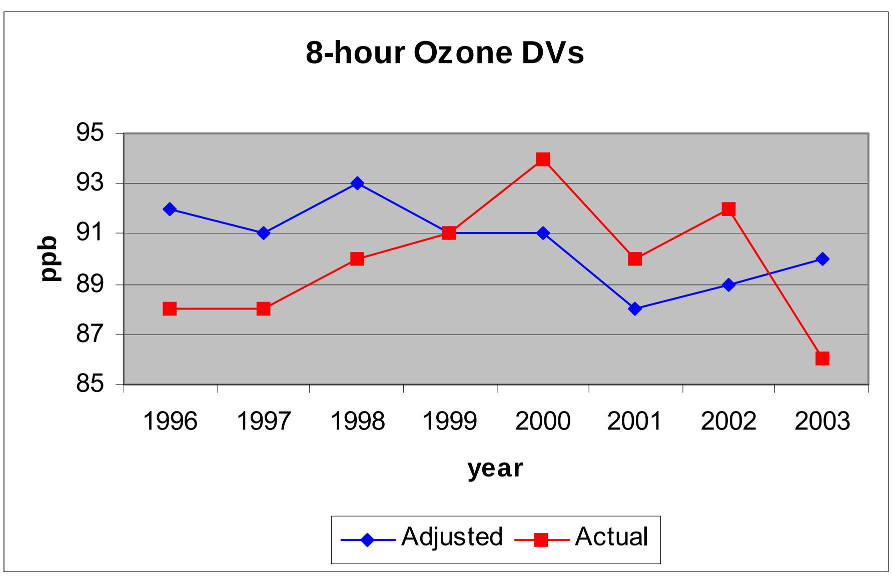
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Tri-Cities area, based on the Kingsport site, are listed in Table 8-20 and plotted in Figure 8-10. Since CART was not applied for the Tri-Cities area as part of the episode selection analysis, we used the meteorological regimes and the CART tree prepared for the Knoxville area as the basis for the adjustment. These area are nearby to each other and have similar geographical features.

Table 8-20.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Tri-Cities

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	88	88	90	91	94	90	92	86
• - 4th highest	85	89	97	89	97	86	93	80
Adjusted								
• - DVs	92	91	93	91	91	88	89	90
• - 4th highest	92	90	97	88	89	87	93	90

Figure 8-10.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Kingsport

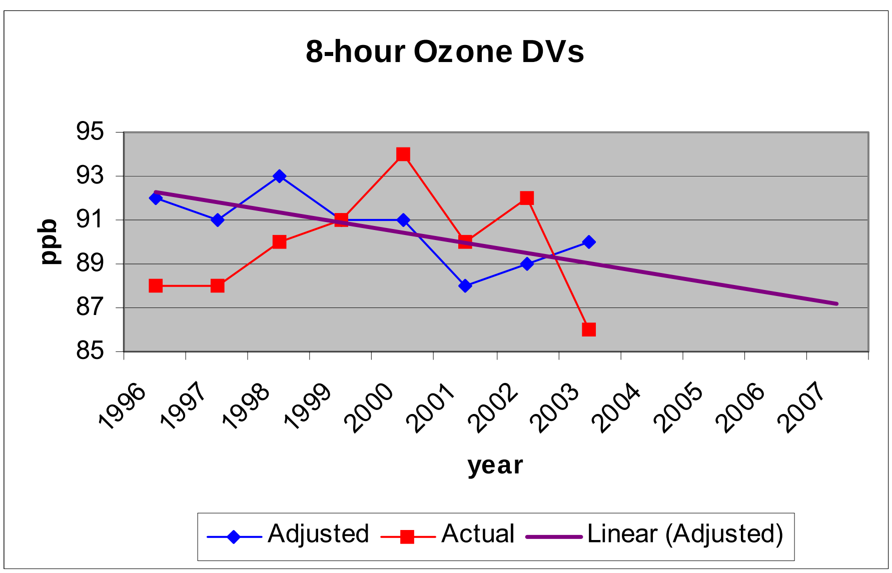


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 90 ppb, one ppb higher than the average actual design value of 89 ppb. The adjusted design values exhibit somewhat less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is slightly more stable than the observation-based design value. The actual values show a clear tendency toward lower design values between 2000 and 2003, while the meteorologically adjusted values show a flatter tendency. The results also indicate that the design value for 2000-2002, as used in the modeled attainment test, may be unrepresentatively high as a result of more days than normal with ozone conducive meteorological conditions during the period and that for 2001-2003 may be unrepresentatively low for the opposite reasons. These results suggest that a more appropriate design value for application of the attainment test is 89 or 90 ppb. Use of a value of 89 ppb in the attainment test results in a 2007 EDV of 82 ppb, whereas use of a value of 90 ppb gives a result of 83 ppb for the EDV. In both cases, the attainment test is passed. This supports a finding of modeled attainment for the Tri-Cities area.

Figure 8-11 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 87 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-11.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Kingsport



Summary Attainment Demonstration for the Tri-Cities Area

The attainment and screening tests and additional corroborative analyses indicate that the Tri-Cities EAC area will be in attainment of the 8-hour ozone standard by 2007. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test. There are no locations within a subdomain encompassing the Tri-Cities EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 50 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

Both of the monitoring sites in the Tri-Cities area have future-year estimated design values for 8-hour ozone that are less than or equal to 84 ppb. The areawide 2007 EDV is 84 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 82 ppb if a meteorologically adjusted design value is used.

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9. Maintenance Analysis for 2012

One of the requirements of the Early Action Compact is to evaluate maintenance of the 8-hour standard for 2012, five years beyond the attainment date of 2007. As such, a 2012 baseline emission inventory was developed for the ATMOS modeling episodes and 2012 baseline simulations were conducted. The development of the 2012 baseline emission inventory followed the same procedures as those used in developing the 2007 emission inventory. Specific details are presented by source category as follows:

Area Sources

- Applied BEA GSP projection factors to base emissions for all states except for the States of Louisiana (used BEA Employment projection factors) and Texas
- Applied energy adjustment factors for fuel combustion sources
- Applied VOC controls included in the Federal control measures, Title III MACT and Title I RACT assumptions
- Applied additional controls for residential wood combustion and Stage II VOC for gasoline service stations
- Eliminated all emissions due to the seasonal ban on open burning in 45 counties in Northern Georgia and 8 Counties in Alabama
- Kept the area source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)
- Applied the same percentage reductions for NO_x, VOC and CO emissions in the EAC counties reflecting area source control measures as specified in the final 2007 EAC attainment strategy (AS-4)

Point Sources

- Applied BEA GSP projection factors to base emissions for all states except for States of Louisiana (used BEA Employment projection factors) and Texas
- Applied energy adjustment factors for the non-EGU fuel combustion sources
- Applied NO_x SIP Call Phase I controls to the EGU and non-EGU sources located in the SIP Call-affected States
- Applied controls included in the CAA and MACT assumptions for non-EGU point sources
- Incorporated 2012 emissions estimates provided by TVA, and assumed that the combustion turbines (CTs) only operate on the three intermediate days of the episode for 4 hours per day (noon to 4pm)
- Incorporated day-specific 2012 emissions estimates provided by Southern Company
- Kept the emissions for the Entergy facilities (located in States of Arkansas, Louisiana and Mississippi) at the base level
- Kept the point source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)

- Kept the emissions at the 2007 levels for the gas compressor stations, Eastman Chemical Company and William Refining & Marketing LLC located in State of Tennessee, and the facilities currently under construction located in State of Mississippi
- Applied the same NO_x and VOC emissions reductions in the EAC counties reflecting to reflecting point source control measures as specified in the final 2007 EAC attainment strategy (AS-4)

Non-Road Mobile Sources

- Used EPA NONROAD2002a model with monthly maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state, except for State of Texas and four counties in Arkansas
- Applied BEA GSP projection factors for emissions from aircraft, railroad and commercial marine vessels (NEI99V2 data) for all states except for States of Louisiana (used BEA Employment projection factors) and Texas
- Projected the 2000 non-road mobile source emissions for the four counties in Arkansas to 2012 level
- Kept the non-road mobile source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)
- Applied the same percentage reductions for NO_x, VOC and CO emissions for the EAC counties reflecting non-road control measures as specified in the final 2007 EAC attainment strategy (AS-4)

On-Road Mobile Sources

MOBILE6.2 with State-specific VMT Data

The mobile source emissions were estimated using MOBILE6.2 with 30-year historical average temperatures and absolute humidity data and state provided 2012 VMT data for Alabama, Arkansas, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee, and Texas.

MOBILE6.2 with FHWA VMT Data

The mobile source emissions for all other states in the ATMOS modeling domain were estimated using MOBILE6.2 with 30-year historical seasonal average temperatures and absolute humidity data, and 2012 FHWA VMT data.

The same percentage reductions were applied for NO_x, VOC and CO emissions for the EAC counties reflecting mobile source control measures as specified in the final 2007 EAC attainment strategy (AS-4).

Summary of Modeling Emission Inventories

The summaries of the 2012 baseline emissions are presented in Appendix B for each modeling episode as follows:

- Table B-34 through Table B-36 for the August/September 1999 episode.
- Table B-37 through Table B-39 for the June 2001 episode.
- Table B-40 through Table B-42 for the July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are tons per day.

Figure 9-1 presents component emission totals for NOx, VOC, and CO for Grid 3 for a typical weekday (18 June 2001) comparing the current year 2001 emissions, the 2007 baseline emissions, and the 2012 baseline emissions. For Grid 3, the expected changes in emissions between 2001 and 2012 result in a 35 percent reduction in anthropogenic NOx emissions, an 18 percent reduction in anthropogenic VOC emissions, and a 20 percent reduction in CO emissions. Figures 7-2 through 7-6 present total emissions for each of the EAC areas for 2001, 2007, and 2012. These plots are presented using the same scale so that the totals can be compared between the EAC areas. The figures indicate that precursor NOx, VOC, and CO emissions in the ATMOS region and in the EAC areas are expected to decrease further in 2012 compared to 2007 as a result of vehicle fleet turnover and a number of new national rules affecting on-road and off-road engine and fuel requirements.

Modeling Results for 2012

The 2012 baseline simulation was conducted for all three of the ATMOS EAC modeling episodes. Table 9-1 presents a comparison of 1-hour and 8-hour metrics for the 2001 current year simulation and the 2012 baseline simulation. Compared to the metrics for the 2007 baseline simulation, the results for 2012 show substantial additional reductions in all of the metrics with reductions from the 2001 current year between 60 and 90 percent. Table 9-2 presents the maximum EDVs for 2012 for all of the EAC areas using both the 2000-2002 and 2001-2003 base year design values. The EDVs for 2012 are lower for all areas by 2 to 4 ppb compared to the 2007 baseline. The modeling results indicate that, despite the expected growth in population between 2007 and 2012, the expected emission reductions reflecting the local EAC measures and national measures provides for further improvement in ozone air quality and maintenance of the 8-hour standard in all of these areas.

Table 9-1a.
Comparison of the ATMOS Current Year (2001) and Future Year Baseline (2012) Simulation Results for All Non-startup Days

Grid/Area	8-hr Exceedance Exposure			# Grid-cells where max 8-hr > 84 ppb		
	2001	2012	% Reduction	2001	2012	% Reduction
Grid 3	4502274	805865	82	41602	9182	78
Memphis EAC	92093	25775	72	766	338	56
Nashville EAC	208109	35284	83	2079	513	75
Knoxville EAC	140359	9459	93	1358	215	84
Chattanooga EAC	204711	23307	88	1741	278	84
Tri-Cities EAC	60247	5635	91	411	124	70

Table 9-1b.
Comparison of the ATMOS Current Year (2001) and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	# Grid Cell Hours where 1-Hr Concs > 84 ppb			1-Hr Exceedances Exposure for Concs > 84 ppb		
	2001	2012	% Reduction	2001	2012	% Reduction
Grid 3	388289	102063	74	3800105	835852	78
Memphis EAC	7514	3244	57	77821	27063	65
Nashville EAC	18777	5741	69	176247	40412	77
Knoxville EAC	11554	2663	77	111972	13555	88
Chattanooga EAC	14858	3109	79	154244	22420	85
Tri-Cities EAC	5015	1240	75	47512	6725	86

Table 9-2.
Maximum Observed and Estimated Design Values (EDVs) for the ATMOS EAC Areas for the 2012 Baseline Simulation

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Memphis EAC (Marion)	94	86	86	92	84	84
Nashville EAC (Rockland Rd.)	88	79	79	86	77	77
Knoxville EAC (Spring Hill)	96	86	86	92	83	82
Knoxville EAC (Clingman's Dome)	98	86	84	92	80	79
Chattanooga EAC (Sequoyah)	93	81	82	87	76	76
Tri-Cities EAC (Kingsport)	92	82	80	86	76	74

Figure 9-1a.
Comparison of NOx Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

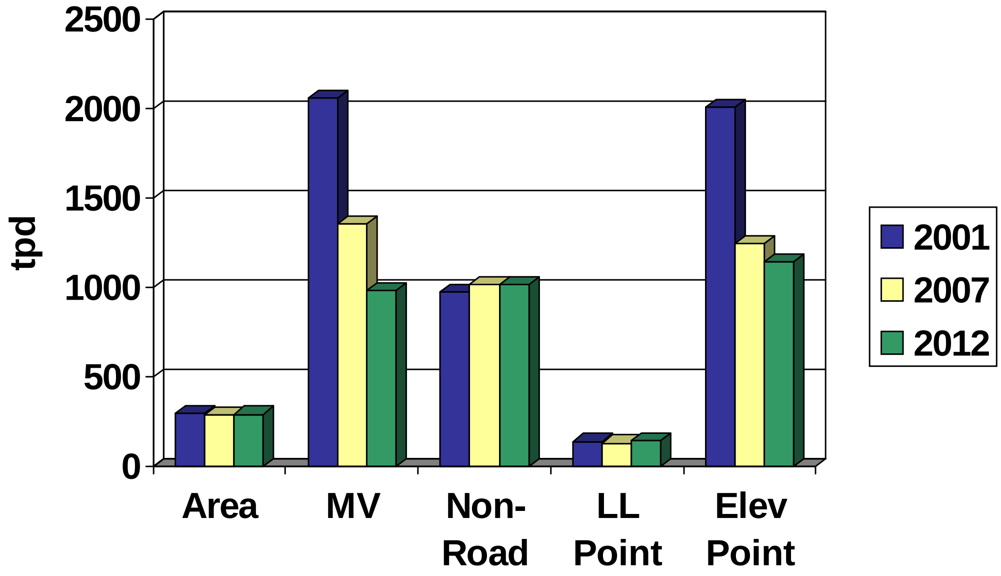


Figure 9-1b.
Comparison of VOC Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

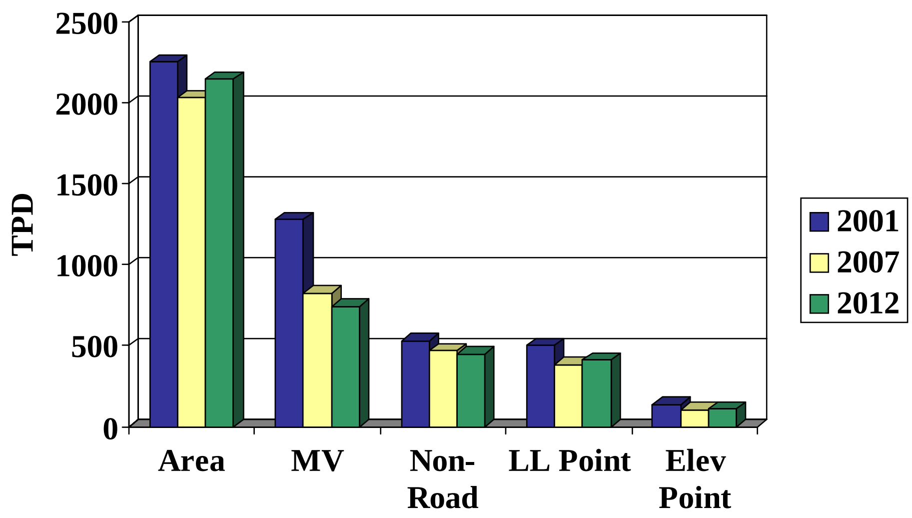


Figure 9-1c.
Comparison of CO Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

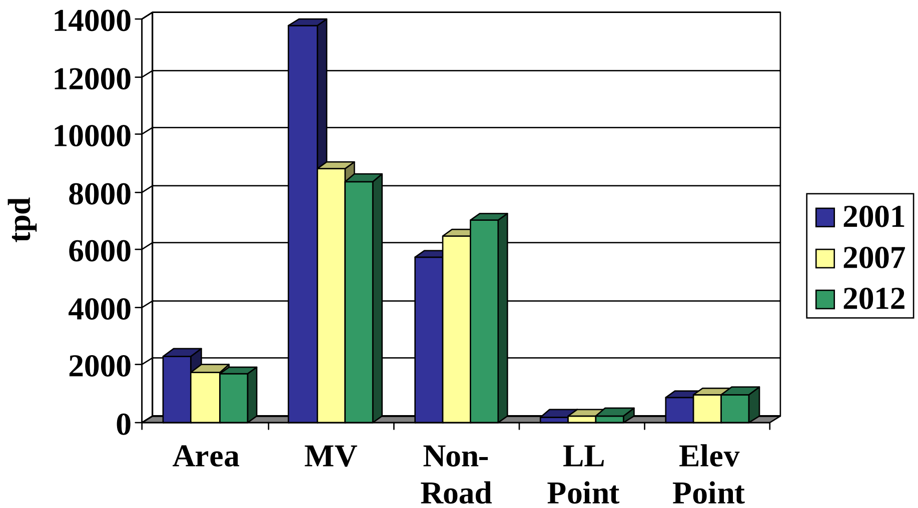


Figure 9-2.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

Emissions for 18 June Episode Day

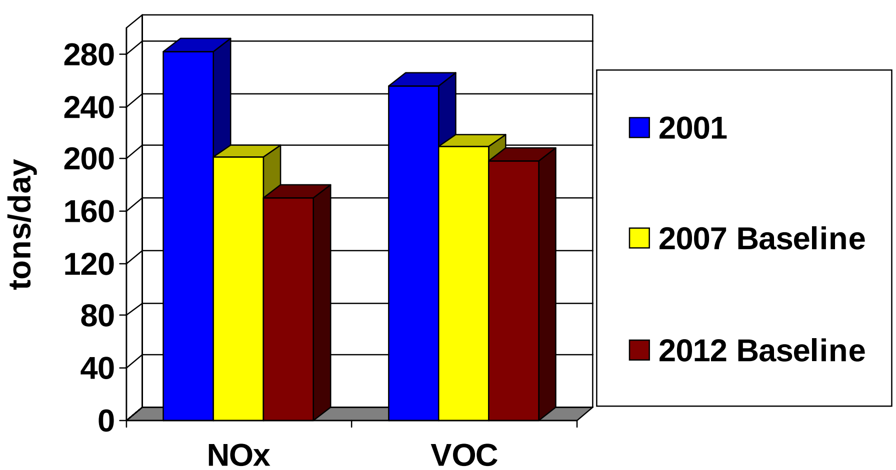


Figure 9-3.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

Emissions for 18 June Episode Day

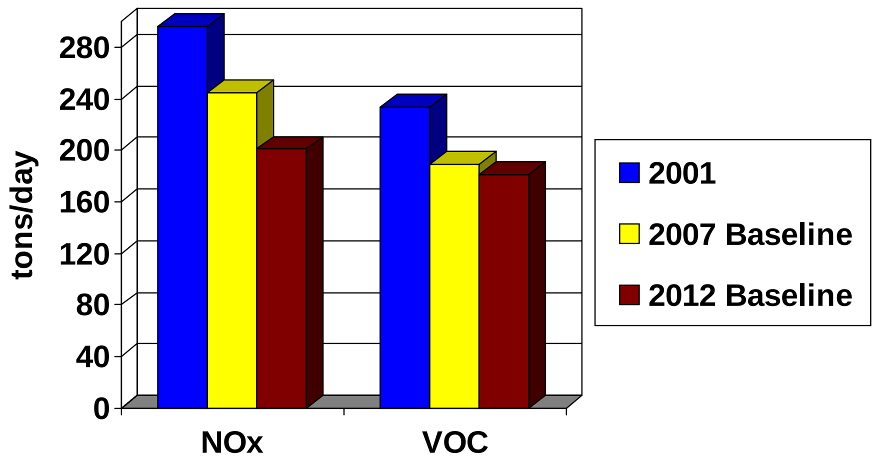


Figure 9-4.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

Emissions for 18 June Episode Day

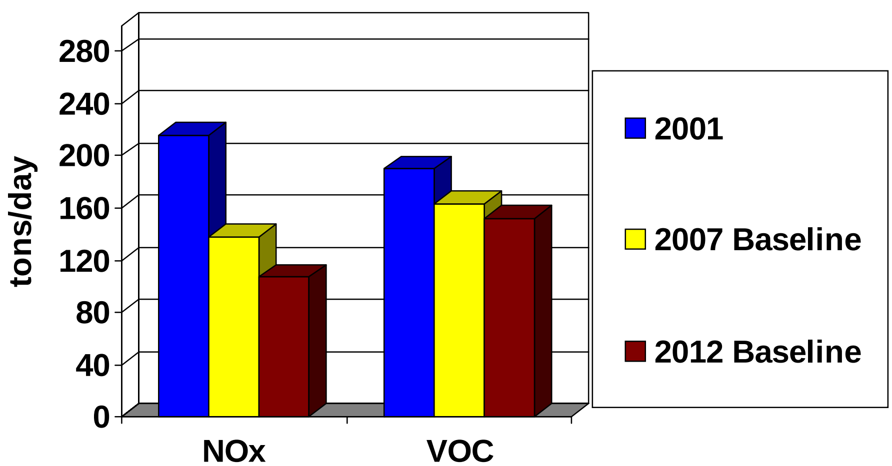


Figure 9-5.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

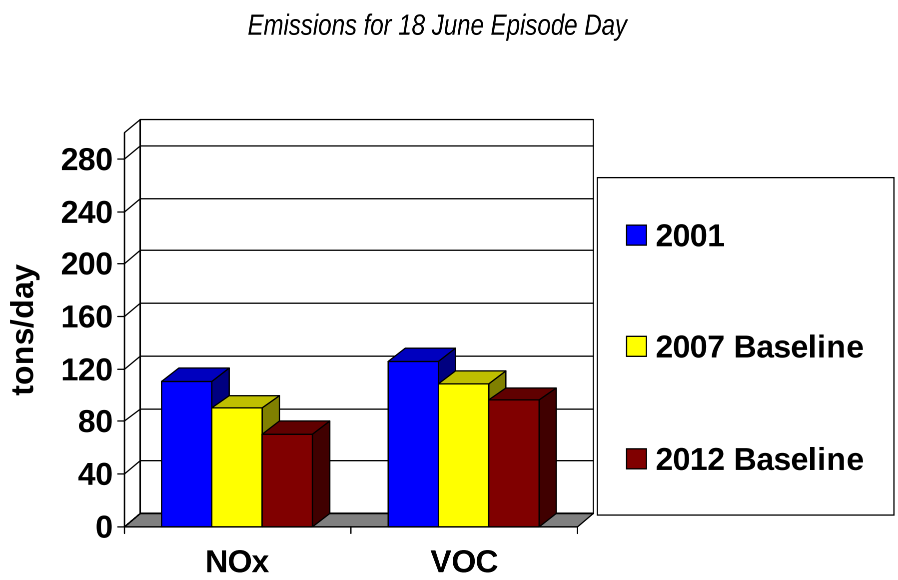
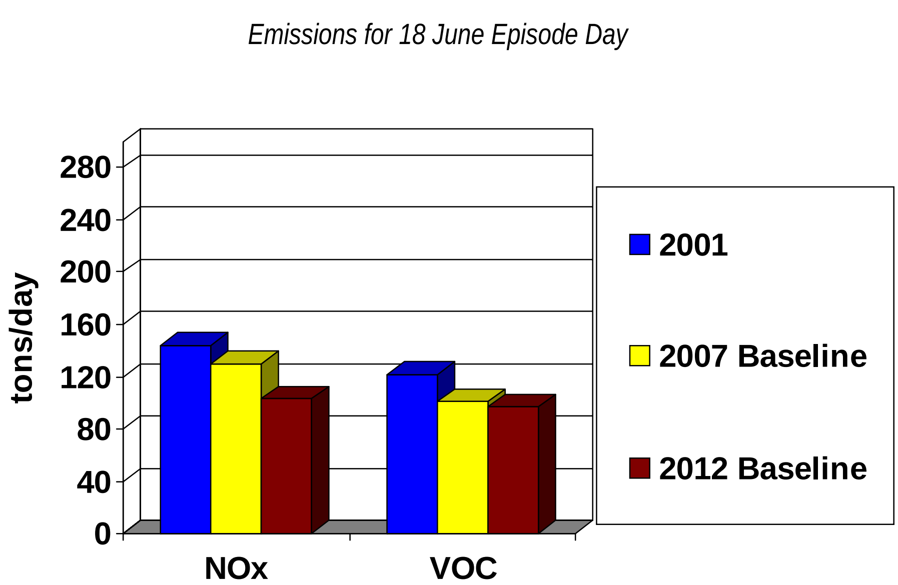


Figure 9-6.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area



10. Summary of Review Procedures Used

The review procedures employed as part of the ATMOS EAC modeling analysis included quality assurance of the modeling inputs and outputs by SAI and the ATMOS technical committee members (with the emphasis for the technical committee on the emissions inputs), and review and analysis of the simulation results by all study participants.

The quality assurance procedures for the modeling system inputs are described in Sections 3, 4, and 5 of this report. Procedures for quality assurance of the simulation results are described in Sections 6 and 7. The ADVISOR database was an important component of the quality assurance review and provided detailed and timely access to the simulation results (and emissions inputs) for all of the modeling analysis participants. In addition, the simulation results were presented to representatives from EPA, Regions 4 and 6 and members of the ATMOS Technical Committee and the general public at meetings held throughout the course of the study (approximately every two to three months).

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11. Data Access Procedures

The data, input, and output files for the modeling analysis are available in electronic format. Interested parties should contact the Tennessee Department of Environment and Conservation, Air Pollution Control Division for information on how to obtain these files. The modeling tools used for this study are all publicly available and can be obtained from EPA (BEIS, MOBILE), NCAR (MM5), or SAI (EPS2.5, UAM-V).

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Appendix A: Early Action Compact Modeling Analysis for the State of Tennessee

Draft Technical Protocol (30 May 2003)

Table of Contents

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1. Introduction and Study Design

This protocol document outlines the methods and procedures to be followed in conducting an Early Action Compact (EAC) 8-hour ozone attainment modeling analysis for the States of Arkansas, Tennessee, and Mississippi. The EAC modeling exercise will leverage off the accomplishments of the Arkansas-Tennessee-Mississippi Ozone Study (ATMOS) modeling analysis, which was originally designed to provide technical information relevant to attainment of an 8-hour National Ambient Air Quality Standard (NAAQS) for ozone primarily in the Memphis, Nashville, and Knoxville areas. In addition, the ATMOS analysis was also to provide information for addressing the emerging 8-hour ozone issues in the Hamilton County (Chattanooga), Tennessee; Lee County (Tupelo), Mississippi; and Little Rock, Arkansas areas.

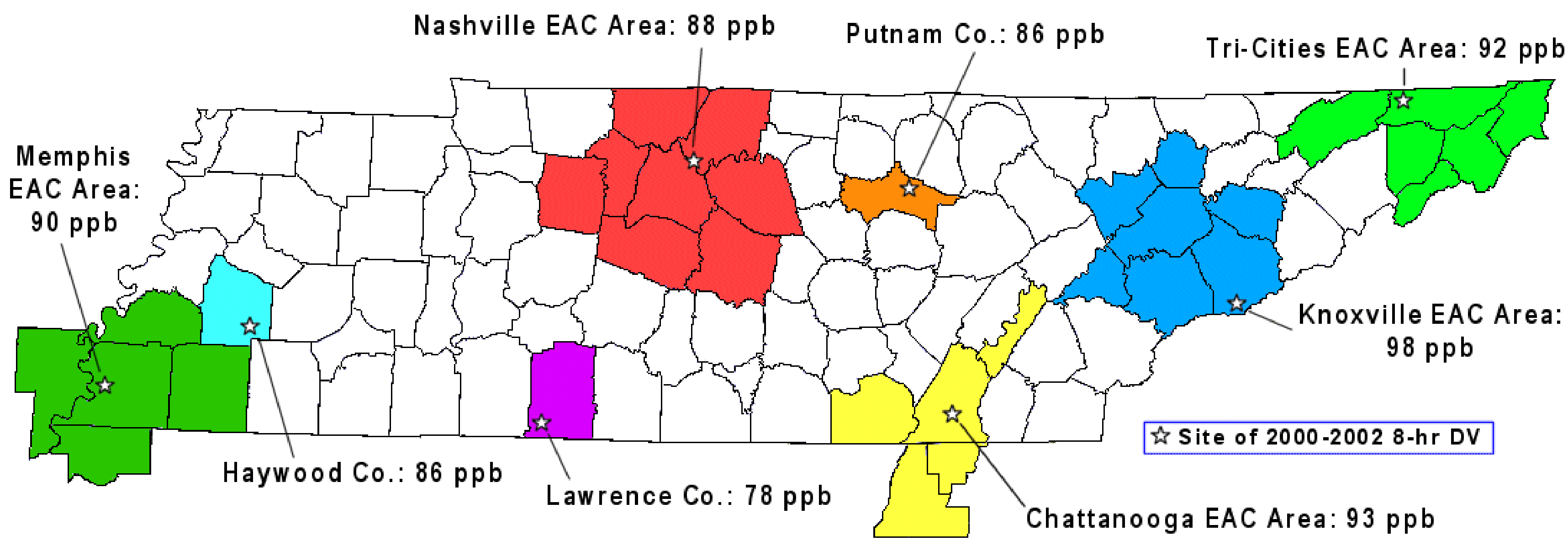
On December 31, 2002, the State of Tennessee entered into Early Action Compact agreements with EPA for eight areas within the state. The EAC areas include 30 counties within Tennessee, 2 adjacent counties in Georgia, and 1 adjacent county each in Arkansas and Mississippi, as well as 7 municipalities. Representatives from each of these jurisdictions signed the EAC. The EAC areas include the following:

- **Nashville EAC Area**: Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson counties.
- **Knoxville EAC Area**: Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson counties
- **Chattanooga EAC Area**: Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa counties, (Georgia)
- **Memphis EAC Area**: Shelby, Tipton, and Fayette counties (Tennessee); Crittenden County, (Arkansas); De Soto County, (Mississippi).
- **Tri-Cities EAC Area**: Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington counties.
- **Haywood County**
- **Lawrence County (Florence, AL MSA)**
- **Putnam County**

A map of the EAC areas, including the 2000-2002 design values for each area, is provided in Figure 1-1.

The existing committee structure and framework established for the ATMOS modeling analysis will be utilized to conduct the EAC modeling, and this protocol will serve as the overall protocol for the modeling to be conducted for each of the EAC areas. Information regarding the organizational structure of ATMOS/EAC, study participants, communication structures, and the resolution of technical difficulties is presented in this section. The goals, objectives, and technical components of the EAC modeling/analysis study are briefly described. Issues related to the study protocol are discussed and a schedule for the study is provided.

Figure 1-1. Tennessee EAC areas with 2000-2002 8-hour design values.



Committee Composition and Responsibilities

Three committees direct the ATMOS/EAC work. The Policy Committee is composed of upper management persons from the state and municipal organizations funding the project. The Operations Committee is composed of persons from the Technical Committee representing the principal states and organizations funding the project. The Technical Committee is composed of persons with technical expertise from the participating entities. In addition, persons representing themselves or organizations not participating in the funding of this study may be members of the Technical Committee. A Memorandum of Understanding (MOU) has been executed among the principal funding entities to effect a common agreement of the scope of work to be completed in ATMOS.

The Policy Committee secures funding for the project, enlists new members from entities wanting to participate in the funding, and makes final judgments on matters that cannot be resolved within the technical committee. The policy committee is made up of representatives from the states of Arkansas, Tennessee, and Mississippi as well as representatives from the Chattanooga, Knoxville, Memphis, and Nashville air programs.

The Operations Committee directs the work of the contractor. The Operations Committee is a subset of the Technical Committee and is composed of a member from each of the policy committee states and organizations drawn from the Technical Committee (including the Chairs) and the project manager (from SESARM) who will collectively approve the work products from the consultant for payment and make final decisions on the work products discussed among the full Technical Committee.

The Technical Committee is a broad-based committee of stakeholders with technical expertise that meets regularly to discuss and takes action on specific tasks to be completed by the contractor. These tasks include, but are not limited to, procedures used to select episodes for modeling, development of appropriate emissions inventories, development of meteorological fields associated with the selected episodes, sensitivity runs of the photochemical grid model, control strategy runs for the photochemical grid model, and presentation of results.

Study Participants and Their Roles

The principal participants in the study are those states and organizations that are funding the study. These include the states of Arkansas, Tennessee, and Mississippi and the cities of Memphis, Nashville, Knoxville, and Chattanooga. In addition, the U.S. Environmental Protection Agency (Regions IV and VI), and other stakeholders (e.g., TVA, Entergy, etc.) also participate.

The role of all the principal participants is somewhat greater than that of the other participants. The principal participants are funding the study and play a more direct role in the day-to-day operations and contact with the contractor. Final decisions on tasks and project management are made by the principal participants through the Operations Committee. The involvement of others is through their active participation on the Technical Committee.

Systems Applications International, Incorporated (SAI), will conduct the ATMOS EAC modeling and analysis tasks under a contract with the Southeast States Air Resource Managers, Inc. (SESARM), which is under the direction of Mr. John Hornback. Jay Haney and Sharon Douglas will serve as co-project managers for SAI.

Communications Structures

Communication among the participants occurs during scheduled face-to-face meetings of the Technical Committee, teleconferences of the Operations Committee, and continuous (as necessary) e-mail and telephone. A Web site set up by the consultant contains information and results generated in the study (see http://atmos.saintl.com).

Communication between the contractor and the participants will be through the contractor's participation in the face-to-face and teleconference meetings, and by an e-mail distribution list. Outside of these meetings, communication between the contractor and the participants will be from the members of the Operations Committee.

SAI will report directly to SESARM and the ATMOS Operations Committee.

Resolution of Technical Difficulties

Technical difficulties encountered by SAI will be brought to the attention of the Operations Committee, either verbally or through written correspondence. SAI will also offer suggestions or recommendations on how to resolve such difficulties. All major issues or difficulties (whether or not they are fully or satisfactorily resolved during the course of the study) will be documented, in either a technical memorandum or the modeling/analysis report.

Goals and Objectives of the Study

The ATMOS/EAC modeling/analysis is designed to provide technical information related to 8-hour ozone issues in the EAC areas located primarily in the State of Tennessee. The EAC modeling provides an opportunity for these areas to conduct photochemical modeling to support decisions regarding control measures that could be adopted earlier than would be required by EPA, once the areas are formally designated nonattainment in 2004 under the new 8-hour National Ambient Air Quality Standard (NAAQS) for ozone. Based on data for 1997-2002, the calculated design values for the areas listed above are given in Table 1-1.

Table 1-1. 1997-2002 Maximum 8-Hour Ozone "Design Values" for the ATMOS EAC Areas of Interest.

	Maximum 8-hour Ozone Design Values (ppb)			
	1997–1999	1998–2000	1999–2001	2000–2002
Nashville EAC Area	102	100	93	88
Knoxville EAC Area	104	104	98[1]	98
Chattanooga EAC Area	94	97	92	93
Memphis EAC Area	95	97	93	94
Tri-Cities EAC Area	91	94	90	92
Haywood County	98	93[2]	89	86
Lawrence County	88	89	83	78
Putnam County	88	91	87	86

The primary objective of this study is to provide the modeling/analysis results needed to support an attainment demonstration for each of these areas. As such, the study has been designed in accordance with draft EPA guidance (EPA, 1999) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes. Note the while the guidance is currently in draft form, the final version is not expected to be substantively different from the draft (EPA, personal communication).

The results of this study will be presented in a single report, with separate sections for the presentation of results for each area of interest. The analytical results will also be presented in electronic/database format such that each of the areas can be examined separately. In this manner, the study results will be easily referenced or directly incorporated into State Implementation Plan (SIP) documentation prepared by the state or local agencies.

Modeling/Analysis Study Components

The ATMOS EAC modeling analysis components include a comprehensive episode selection analysis (identifying suitable periods for modeling), application and evaluation of a photochemical modeling system for two simulation periods, projection of emissions and ozone concentrations for two future years, and evaluation of ozone attainment strategies. All technical tasks will be conducted in accordance with draft EPA guidance regarding the use of modeling and other analyses for 8-hour ozone attainment demonstration (EPA, 1999). The documentation prepared as part of this study will be appropriate for inclusion as part of a SIP technical support document for each of the areas of interest.

[1] Look Rock (470090101-2) operated for 1999 only. Based on one year of data, design value would be 104 ppb.

[2] Site 4707500021 closed in 1999. Based on one year of data, the design value would be 98 ppb.

Protocol Objectives, Contents, and Amendment Procedures

This protocol document should be viewed as a set of general guidelines and is intended to provide focus, consistency, and a basis for consensus for all parties involved in the study.

The primary purpose of the protocol document is to outline the methodologies to be followed throughout the study. At this time some of the methodologies to be used in the modeling/analysis study have not been finalized. It will be necessary for the study participants to make decisions regarding these issues as the study progresses. Amendment of the protocol document will occur only upon the direction of the ATMOS Operations Committee. Each time the protocol document is amended, a revised version of the entire document will be made available in electronic format on the ATMOS web site.

The remainder of this document provides detailed information on each element of the modeling/analysis. Selection of the primary modeling tools is summarized in Section 2 and a brief overview of each is provided. The methods and results of the episode selection analysis are provided in Section 3. The modeling domain is presented in Section 4. Model input preparation procedures are described in Section 5. Model performance evaluation is discussed in Section 6. The use of diagnostic and sensitivity analysis is outlined in Section 7. Future-year modeling is discussed in Section 8. A description of the attainment demonstration procedures is given in Section 9. Documentation procedures are detailed in Section 10. The deliverables and schedule for the project are summarized in Section 11. Archival and data acquisition procedures are outlined in Section 12.

Schedule

A schedule for the ATMOS/EAC modeling analysis is provided in Figure 1-2.

Figure 1-2. Proposed timeline for completion of the ATMOS/EAC photochemical modeling analysis.

APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN
Modeling Protocol & Episode Selection									
Emission inventory development									
	Base Case Emissions								
			Current-yr Emissions						
			Future-yr Emiss. (2007 & 2012)						
Modeling									
			Base Case Modeling & Performance Evaluation						
				Current-yr Modeling					
				Future-yr Baseline Modeling (2007 & 2012)					
					Future-year Modeling Analysis				
Report preparation									
						Draft Final Report		D	
								Final Report	F
Meetings									
			M		M		M		

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2. Model Selection

The selection of modeling tools for this study considered (1) technical formulation, capabilities, and features, (2) comprehensiveness of testing, and (3) demonstrated successful use in previous applications (similar in scope to the ATMOS analysis). The primary modeling tools selected for use in this study include: the variable-grid Urban Airshed Model (UAM-V), a regional- and urban-scale, nested-grid photochemical model; the Emissions Preprocessing System (EPS2.5), for preparation of model ready emission inventories; the Biogenic Emission Inventory System (BEIS), for estimating biogenic emissions; the MOBILE model, for estimating motor-vehicle emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The rationale for selecting each of these modeling tools (in keeping with EPA guidance) is discussed in this section; an overview of each modeling tool is also provided.

Selection and Overview of the Photochemical Model

The UAM-V modeling system (Version 1.5) was selected for use in this study. The UAM-V is a state-of-the-science photochemical modeling system that incorporates the latest version of the Carbon-Bond chemical mechanism (Carbon Bond 5 (CB-V)), incorporating the most current updates to the mechanism (SAI, 2002). It is designed for the regional- and urban-scale simulation of the physical and chemical processes that determine the spatial and temporal distribution of ozone and precursor pollutants within the atmospheric boundary layer. It is typically applied for multi-day simulation (or episode) periods. Key features of the UAM-V modeling system that are relevant to its use in this study include multiple nested-grid capabilities, ability to explicitly incorporate output from a dynamic meteorological model, a detailed plume-in-grid (P-i-G) treatment for emissions from elevated point sources, and the accommodation of process-level analysis of the simulation results. The UAM-V modeling system is currently the most widely used and comprehensively tested photochemical modeling system in the world and its utility for both regional- and urban-scale analysis has been successfully demonstrated in dozens of applications (e.g., regional-scale modeling of the eastern U.S. as part of the Ozone Transport Assessment Group (OTAG) modeling study, SIP modeling of the Atlanta ozone nonattainment area by the Georgia Department of Natural Resources, and 8-hour regional modeling as part of the Gulf Coast Ozone Study (GCOS)).

EPA (1999) lists five factors to be considered in selecting a model for use in an 8-hour ozone attainment demonstration. These are listed (in bold) and discussed in the following text.

- **Nature of the air quality problem leading to nonattainment of the ozone NAAQS should first be assessed, and the selected model should have the attributes and capabilities consistent with the perceived nature of the problem**. Based on an analysis of the observed data (included as part of the episode selection analysis), the potential ozone nonattainment problem for the areas of interest appears to have both regional and local components. The data also indicate that high ozone concentrations are not confined to the urban areas and that the higher concentrations are often downwind of the urban areas and/or at higher elevation sites. Thus, terrain and meteorological influences are likely important. The UAM-V modeling system is well suited for this application in that it is a regional- and urban-scale model (with nested-grid capabilities) and accommodates the use of detailed meteorological inputs from a dynamic meteorological model. The nested-grid feature will enable the use of a large domain so that any influence from surrounding areas can be directly simulated, yet will accommodate high resolution over the areas of interest.

The use of detailed meteorological inputs will enable representation of the important mesoscale meteorological features such as the regional- and local transport patterns, terrain-induced airflow patterns, and vertical mixing patterns. The process-analysis feature of the UAM-V modeling system will enable an assessment of model performance at the process level and thus a comparison of the simulation results relative to available conceptual models of ozone formation (e.g. from intensive measurement studies for Nashville).

- **Availability, documentation, and past performance should be satisfactory.** The UAM-V modeling system is available at no cost, is fully documented, and has been demonstrated to perform satisfactorily in more than ten recent applications. Several references are provided later in this section. More are available upon request.
- **Relevant experience of available staff and contractors should be consistent with choice of a model.** The modeling tasks will be performed by SAI staff who are knowledgeable and experienced in the application of the UAM-V modeling system.
- **Time and resource constraints may be considered.** Use of the UAM-V modeling system is consistent with the time and resource constraints of the ATMOS modeling study.
- **Consistency of the model with what was used in adjacent regional applications should be considered.** The UAM-V modeling system was used for the OTAG regional-scale modeling effort and is currently being used for regional- and urban-scale modeling of Baton Rouge, Lake Charles, Shreveport, the Gulf Coast area, and areas within the State of South Carolina. It is currently being used for EAC modeling of South Carolina and Shreveport, Louisiana. It has been used by the Texas Commission on Environmental Quality and the Tennessee Valley Authority for regional or subregional modeling of their respective areas. It was also used by the Minerals Management Service (MMS) for modeling of the effects of emissions from offshore oil and gas production on the Gulf Coast area (Haney et al., 1995), a study explicitly called for in the Clean Air Act Amendments of 1990.

Overview of the UAM-V Modeling System

The variable-grid Urban Airshed Model (UAM-V) is a three-dimensional photochemical grid model that calculates concentrations of pollutants by simulating the physical and chemical processes in the atmosphere. The basis for the UAM-V is the atmospheric diffusion or species continuity equation. This equation represents a mass balance that includes all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes in mathematical terms.

The major factors that affect photochemical air quality include:

- the pattern of emissions of NO_x and volatile organic compounds (VOC), both natural and anthropogenic
- composition of the emitted VOC and NO_x
- spatial and temporal variations in the wind fields
- dynamics of the boundary layer, including stability and the level of mixing
- chemical reactions involving VOC, NO_x, and other important species
- diurnal variations of solar insolation and temperature

- loss of ozone and ozone precursors by dry and wet deposition
- ambient background of VOC, NO_x, and other species in, immediately upwind of, and above the study region.

The UAM-V simulates all of these processes. The species continuity equation is solved using the following fractional steps: emissions are injected; horizontal advection/diffusion are solved; vertical advection/diffusion and deposition are solved; and chemical transformations are performed for reactive pollutants. The UAM-V performs these four calculations during each time step. The maximum time step is a function of the grid size, maximum wind velocity, and diffusion coefficient. The typical time step is 10–15 minutes for coarse (10–20 km) grids and a few minutes for fine (1–2 km) grids.

Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is ideal for evaluating the air-quality effects of emission control scenarios. This is achieved by first replicating a historical ozone episode to establish a base-case simulation. Model inputs are prepared from observed meteorological, emissions, and air quality data for the episode days using prognostic meteorological modeling and/or diagnostic and interpolative modeling techniques. The model is then applied with these inputs, and the results are evaluated to determine model performance. Once the model results have been evaluated and determined to perform within prescribed levels, the same base-case meteorological inputs are combined with *modified* or *projected* emission inventories to simulate possible alternative/future emission scenarios.

The UAM-V modeling system incorporates the Carbon-Bond IV chemical mechanism with enhanced isoprene chemistry. It represents an extension of the UAM (also referred to as UAM-IV). Features of the UAM-V modeling system include:

1. *Variable vertical grid structure:* The structure of vertical layers can be arbitrarily defined. This allows for higher resolution near the surface and facilitates matching with output from prognostic meteorological models.
2. *Three-dimensional meteorological inputs:* The meteorological inputs for UAM-V vary spatially and temporally. These are usually calculated using a prognostic meteorological model.
3. *Variable grid resolution for chemical kinetic calculations:* A chemical aggregation scheme can be employed, allowing chemistry calculations to be performed on a variable grid while advection/diffusion and emissions injections are performed on a fixed grid.
4. *Two-way nested grid:* Finer grids can be imbedded in coarser grids for more detailed representation of advection/diffusion, chemistry, and emissions. Several levels of nesting can be accommodated.
5. *Updated chemical mechanism:* The original carbon bond chemical mechanism has been updated with the inclusion of Carbon Bond 5, (CB-V), which has included enhancements to some of the chemical reactions in the CB-IV version of the mechanism.
6. *Dry deposition algorithm:* The dry deposition algorithm is similar to that used by the Regional Acid Deposition Model (RADM).
7. *True mass balance:* Concentrations are advected and diffused in the model using units of mass per unit volume rather than parts per million. This maintains true mass balance in the advection and diffusion calculations.

8. *Plume-in-grid treatment:* Emissions from point sources can be treated by a subgrid-scale Lagrangian photochemical plume model. Pollutant mass is released from the subgrid-scale model to the grid model when the plume size is commensurate with grid cell size.
9. *Plume rise algorithm:* The plume rise algorithm is based on the plume rise treatment for a Gaussian dispersion model.
10. *Oxidant tagging capabilities:* Provides ozone contribution analysis information (Ozone Precursor Tagging Methodology (OPTM)) by precursor (NOx and VOC), source category, or geographic region, which is useful in designing and testing effective emission reduction strategies.

Acceptability Relative to the EPA "Alternative Model" Requirements

In accordance with draft EPA guidance (EPA, 1999), use of the UAM-V modeling system for this study represents the use of an "alternative model" for 8-hour ozone attainment demonstration purposes. It is available to the public at no cost and is not proprietary. Use of the UAM-V modeling system further satisfies the third condition offered by EPA in the guidance document, which requires that the alternative model "is more appropriate than the preferred model for a given application or there is no preferred model." In this case, there is no "preferred" model (EPA, 1999). In the draft guidance document, EPA provides six criteria for a model to qualify as a candidate for use in an attainment demonstration. These are listed (in bold) and compliance with each is established in the following text.

- **The model has received a scientific peer review.** A formal scientific peer review of the UAM-V modeling system was conducted by ENSR (1993). Since that time, hundreds of scientists and modelers have reviewed the modeling system code as a routine part of their work with the modeling system.
- **The model can be demonstrated applicable to the problem on a theoretical basis.** As noted in the previous section, the UAM-V modeling system represents (either explicitly or implicitly) the physical and chemical processes that are currently known to influence the formation and transport of ozone as well as the emission, chemical transformation, and dispersion of ozone precursor pollutants. The features and capabilities of the modeling system are consistent with the application on both regional and urban scales, as required for this study.
- **Databases needed to perform the analysis are available and adequate.** The UAM-V modeling system requires several different types of input data files. These will be prepared using available data and EPA-recommended techniques. Their adequacy for use with the modeling system will be assessed as part of the modeling study.
- **Available past appropriate performance evaluations have shown the model is not biased toward underestimates.** Past applications of the UAM-V modeling system do not indicate a bias toward underestimation. Some examples of recent applications include OTAG, 1997; BAAQMD, 1998; and Douglas et al., 1998 as well as the GCOS modeling analysis (SAI, 2001). Each of these applications includes several days and day-to-day variations in model performance, but a consistent bias toward underestimation is not indicated.
- **A protocol on methods and procedures to be followed has been established.** The protocol is outlined in this document. The modeling will be conducted in a manner that is

consistent with established practice and EPA guidelines regarding air quality modeling related to the 8-hour ozone standard.

- **The developer of the model must be willing to make the model available to users for free or for a reasonable cost, and the model cannot be proprietary.** The version of the UAM-V to be used for this study is available from SAI (the developer of UAM-V) at no cost. The UAM-V is not a proprietary model and as such complies with each element of the definition put forth recently by the North American Research Study of Tropospheric Ozone (NARSTO).

Selection and Overview of the Emissions Modeling and Processing Tools

The EPS2.5, BEIS, and MOBILE emissions processing/modeling tools were selected for use in this study. EPS2.5 is an extended version of EPS (EPA, 1992a) that has been enhanced to facilitate the preparation of regional-scale emission inventories. BEIS-2 is the latest available version of the EPA biogenic emission estimation model. Note that the UAM-V modeling system includes a representation of isoprene chemistry that is consistent with the use of BEIS-2. MOBILE6 is the current version of the EPA tool for calculation of on-road motor vehicle emissions.

EPA (1999) lists five factors to be considered in selecting a model for use in an 8-hour ozone attainment demonstration. These are listed (in bold) and discussed in the following text.

- **Nature of the air quality problem leading to nonattainment of the ozone NAAQS should first be assessed, and the selected model should have the attributes and capabilities consistent with the perceived nature of the problem.** Use of EPS2.5 facilitates the preparation of a regional-scale emission inventory, as needed for this study. BEIS is currently the recommended tool for estimation of biogenic emissions, which are likely to play an important role in ozone formation within the Tennessee Valley area. The latest available version of BEIS will be used. As noted earlier, MOBILE is the model developed and recommended by EPA for calculating emissions from on-road mobile sources. Use of this tool facilitates the use of the county- and parish-specific estimates of vehicle miles traveled (VMT) and detailed temperature information available for this study. The latest available version of MOBILE will be used for this study.
- **Availability, documentation, and past performance should be satisfactory.** EPS2.5, BEIS, and MOBILE are available for free and are fully documented. These tools have been used successfully in more than five recent applications including OTAG (1997) and sub-regional modeling of the southeastern U.S. (Douglas et al., 1998). Additional references are available upon request.
- **Relevant experience of available staff and contractors should be consistent with choice of a model.** The modeling tasks will be performed by SAI staff who are knowledgeable and experienced in the application of EPS2.5, BEIS-2, and MOBILE6.
- **Time and resource constraints may be considered.** Use of EPS2.5, BEIS, and MOBILE is consistent with the time and resource constraints of the ATMOS/EAC modeling study.
- **Consistency of the model with what was used in adjacent regional applications should be considered.** EPS2.5, BEIS-2, and MOBILE6 are currently being used for

regional- and urban-scale modeling of the Baton Rouge, Gulf Coast, and South Carolina areas. EPS2.5 was also used by the Minerals Management Service (MMS) for modeling of the effects of emissions from offshore oil and gas production on the Gulf Coast area. BEIS-2 was used for the OTAG regional-scale modeling effort.

Overview of the EPS2.5

EPS2.5 is a series of FORTRAN modules that perform the intensive data manipulations required to incorporate spatial, temporal, and chemical resolution into an emission inventory used for photochemical modeling. It enables the user to conform to EPA emission inventory requirements, and evaluate proposed control measures for meeting required emission reductions. EPS2.5 provides emission inputs to the UAM-V; specific features and capabilities related to the UAM-V application are described in Section 5 of this protocol document.

Overview of BEIS-2

BEIS-2 is a computer algorithm used to generate biogenic emissions for air quality simulation models, such as UAM-V. Emission sources that are modeled include volatile organic compound (VOC) emissions from vegetation and nitric oxide (NO) emissions from soils. BEIS-2 includes an up-to-date, county-level biomass database and emission factors for a variety of plant species. It accommodates the use of solar-radiation information in calculating emission rates.

Overview of MOBILE6

The EPA's highway vehicle emission factor model, MOBILE6, is a FORTRAN program that provides average in-use fleet emission factors for volatile organic compounds (VOC), oxides of nitrogen (NO_x) and carbon monoxide (CO) for eight categories of vehicles, for any calendar year between 1970 and 2020 and under various conditions affecting in-use emission levels (e.g., ambient temperatures, average traffic speeds, gasoline volatility) as specified by the model user. It has been used in evaluating control strategies for highway mobile sources, by States (except California) and other local and regional planning agencies in the development of emission inventories and control strategies for SIPs, for conformity issues related to Transportation Improvement Plans (TIPs), and in the development of environmental impact statements (EIS). This version of the model was released by EPA in Spring 2002.

Selection and Overview of the Meteorological Model

The MM5 meteorological modeling system was selected for use in this study. MM5 is a state-of-the-science dynamic meteorological modeling system that has been used in several previous air quality modeling applications. Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, detailed treatment of the planetary boundary layer, and the ability to accurately simulate features with non-negligible vertical velocity components, such as the gulf breeze (a non-hydrostatic option). The MM5 modeling system is widely used and is currently supported by NCAR. Its use in conjunction with the UAM-V modeling system has been successfully demonstrated as part of a regional- and urban-scale modeling application for the southeastern U.S. (Douglas et al., 1998).

EPA (1999) lists five factors to be considered in selecting a model for use in an 8-hour ozone attainment demonstration. These are listed (in bold) and discussed in the following text.

- **Nature of the air quality problem leading to nonattainment of the ozone NAAQS should first be assessed, and the selected model should have the attributes and capabilities consistent with the perceived nature of the problem.** The MM5 modeling system should enable a physically realistic simulation of the meteorological features that characterize the study area and episode period, including terrain-induced airflows and summertime vertical mixing/inversion features. The nested-grid feature will support the preparation of inputs for a regional- and urban-scale application of UAM-V.
- **Availability, documentation, and past performance should be satisfactory.** The MM5 modeling system is free and documentation is available. It has been used in conjunction with UAM-V to support regional- and urban-scale modeling of the southeastern U.S. and has been used for several other air quality modeling studies (e.g., for California's San Joaquin Valley and the eastern Gulf Coast area). Versions of the modeling system have been used for the past two decades to support research in the area of mesoscale meteorology.
- **Relevant experience of available staff and contractors should be consistent with choice of a model.** The modeling tasks will be performed by SAI staff who are knowledgeable and experienced in the application of the MM5 modeling system.
- **Time and resource constraints may be considered.** Use of the MM5 modeling system is consistent with the time and resource constraints of the ATMOS modeling study.
- **Consistency of the model with what was used in adjacent regional applications should be considered.** MM5 was recently used for regional- and urban-scale modeling of the southeastern U.S., with emphasis on Atlanta, Birmingham, and the eastern Gulf Coast.

Overview of MM5

A general description of this three-dimensional, prognostic meteorological model is found in Anthes and Warner (1978). The governing equations include the equations of motion, the continuity equations for mass and water vapor, and the thermodynamic equation. Those features relevant to this application are briefly described in this section.

The current version of MM5 can be applied in a non-hydrostatic mode for the improved simulation of small-scale vertical motions (such as those associated with the sea breeze and terrain effects). Use of this optional feature can be important to the accurate simulation of the airflow and other features at high horizontal resolution and will be utilized for this study.

The MM5 model employs the sigma vertical coordinate: $\sigma = (p - p_t)/(p_s - p_t)$, where p is pressure, p_t is the constant pressure specified as the top of the modeling domain, and p_s is the surface pressure. The sigma-coordinate surfaces follow the variable terrain. The governing equations are integrated over a grid that is staggered in the horizontal and vertical (Messinger and Arakawa, 1976). In the horizontal, the u and v wind components are calculated at points that are staggered with respect to those for all other variables. In the vertical, vertical velocity is defined at the sigma levels while all other variables are defined at intermediate sigma levels.

The MM5 modeling system also supports the use of multiple nested grids. This feature is designed to enable the simulation of any important synoptic scale features at coarser resolution, while incorporating a high-resolution grid over the primary area(s) of interest. In this manner, the computational requirements associated with use of a high-resolution grid over a large domain are avoided. A one-way nesting procedure in which information from the simulation of each outer grid is used to provide boundary conditions for the inner grids is generally recommended and will be used for this application.

To facilitate the realistic simulation of processes within the atmospheric boundary layer, variable surface parameters (including albedo, roughness length, and moisture availability) and a high-resolution planetary boundary layer (PBL) parameterization may be specified. The PBL parameterization also requires use of a multi-layer soil temperature model (an otherwise optional feature of MM5). For the coarse grids, several cumulus parameterization schemes are available to parameterize the effects of convection on the simulated environment. Several explicit moisture schemes are available for high-resolution grids.

The MM5 model supports four-dimensional data assimilation (FDDA), a procedure by which observed data are incorporated into the simulation. FDDA option include (1) “analysis nudging” in which the simulation variables are relaxed or “nudged” toward an objective analysis that incorporates the observed data and (2) “obs nudging” in which the variables are nudged toward individual observations.

The MM5 modeling system has been modified to include the output of the internally calculated vertical exchange coefficients (K_v) for use with UAM-V.

3. Episode Selection

Episode selection for the ATMOS modeling/analysis was based on a review of historical meteorological and air quality data, and application of an objective procedure for optimizing representation of typical ozone exceedance events across the areas of interest. The episode selection analysis was focused on Memphis, Nashville, and Knoxville. The applicability of the episodes selected for these areas for modeling of Chattanooga, Tupelo, and Little Rock was also examined. The original episode selection exercise conducted in 2000 examined data through 1999, and resulted in the selection of the original ATMOS episode (29 August—9 September 1999). As part of the EAC modeling, the episode selection analysis was re-done using data through the year 2002 to select an additional episode to complement the 1999 episode.

The primary objective of the episode selection analysis was to identify suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the Memphis, Nashville, and Knoxville areas. Important considerations include (1) representing the range of meteorological conditions that accompany ozone exceedances, (2) representing the ozone concentration levels that characterize the nonattainment problem (and result in the designation of nonattainment), and (3) accounting for the frequency of occurrence of the relevant meteorological/air quality events (to avoid using results from infrequent or extreme events to guide the decision making process).

The approach to episode selection is consistent with current (draft) EPA guidance (EPA, 1999) on episode selection for 8-hour ozone attainment demonstration modeling. In this guidance, EPA lists the following as the most important criteria for choosing episodes:

- Monitored ozone concentrations comparable to the severity as implied by the form of the NAAQS
- Representation of a variety of meteorological conditions observed to correspond to monitored ozone concentrations of the severity implied by the form of the NAAQS
- Data availability
- Selection of a sufficient number of days so that the modeled attainment test is based on several days

EPA also provides several additional (secondary) criteria for episode selection:

- Episodes used in previous modeling exercises
- Episodes drawn from the period on which the current design value is based
- Observed concentrations are “close” to the design value for as many sites as possible
- Episodes are appropriate for as many of the nonattainment areas as possible (when several areas are being modeled simultaneously)
- Episodes include weekend days

Methodology

The methodology used for the episode selection analysis was based on that developed for a similar study by Deuel and Douglas (1998) and used for the several other modeling studies including GCOS (Douglas et al. 1999). A detailed description of the methods and results is presented by Douglas et al. (2000). For the original episode selection of Memphis, Nashville, and Knoxville, days within the period 1990 to 1999 were classified according to meteorological and air quality parameters using the Classification and Regression Tree (CART) analysis technique.

The frequency of occurrence of ozone exceedances for each classification type was then determined for each area of interest. Days with maximum ozone concentrations within approximately 10 ppb of the respective design value were also identified. Design values were calculated for each area on a site-specific basis. For each area, the "regional" design value was then specified to be the maximum value among all sites in the area. For 8-hour ozone, the design value is the average of the fourth highest daily maximum concentration for each of the three years of the calculation period.

Next, an optimization procedure was applied to the selection of multi-day episodes for maximum achievement of the specified episode selection criteria (as outlined above). A combined optimization was performed for the three primary areas of interest.

Finally, a more detailed analysis of the episode days with respect to the location and number of exceedance sites as well as local meteorological conditions was conducted. The suitability of the episodes for modeling of Chattanooga, Tupelo, and Little Rock was also examined. Among these three areas, meteorological representativeness was only examined for Chattanooga (using CART results from a previous study).

In selecting a new episode for the EAC modeling, data for the years 2000, 2001, and 2002 were added to the CART database and the algorithm was re-run.

Results—Original ATMOS Episode

In accordance with EPA guidance, the primary objectives of the episode selection analysis were to identify days that (1) represent the types of meteorological conditions that are most frequently associated with ozone exceedances and (2) have ozone concentrations that are representative of the design value. The guidance quantifies the latter with a range of 10 ppb.

In addition, several other considerations were used to guide the selection of multiple episode periods for modeling.

- It is important that the candidate modeling episode days encompass the range of meteorological conditions that accompany ozone exceedances (i.e., that all key meteorological regimes, or as many as feasible, are included).
- EPA guidance suggests that a modeling attainment test should include several days. For this analysis, this is assumed to be the number of days with maximum 8-hour ozone within 10 ppb of the design value for each area.
- Since the response of the modeling system to emission reductions can vary according to concentration level, some consideration was given to ensuring that the values within 10 ppb of the design were distributed about the design value and that several exceedance days were included for each area.

The episode selection algorithm was applied to the identification of candidate 8-hour ozone modeling episodes for the three areas of interest. As noted earlier, the objective was to identify episodes that are characterized by typical (frequently occurring) meteorological conditions, and maximum ozone concentrations that are close to the regional design values for the 1997-1999 period. In preparing this protocol document, we have also considered the design value for the 1998-2000 period. Each area was considered separately and as part of an integrated analysis. The integrated analysis was designed such that the selected episode days are representative of not just one, but two or more of the regions included in the analysis.

Following application of the objective episode selection procedures, a final set of episode days was selected such that (1) the best candidate modeling episodes (i.e., those best meeting the representativeness criteria given above) were included, (2) the significant meteorological regimes were represented, and (3) only episodes that occurred during 1997-1999 were included in the final list of candidate episodes. This was done for each ozone metric separately and for the integrated analysis.

In comparing the individual-area results with the integrated results, we found that some days that are good modeling candidates for one area are not good for another area and the best episodes for modeling all three areas may not represent the first choice for each area individually. Considering the criteria given above, the best overall candidate episode originally selected for the ATMOS modeling is 29 August—9 September 1999. This rather long simulation period includes multiple days of interest for all three areas. The meteorological and air quality characteristics of the this set of days are summarized in Table 3-1 for Memphis, Nashville, and Knoxville.

Table 3-1a. SUMMARY of Maximum 8-Hour Ozone Concentration and Meteorological Regime for the 29 August–9 September 1999 Episode Days for Memphis.

Exceedances and key meteorological regimes (CART bins) are highlighted in bold.

Year	Month	Day	Maximum 8-Hour Ozone (ppb)	CART Bin[3]
1999	8	29	79	22
1999	8	30	71	20
1999	8	31	96	15
1999	9	1	87	21
1999	9	2	95	34
1999	9	3	97	18
1999	9	4	106	29
1999	9	5	64	35
1999	9	6	80	2
1999	9	7	87	26
1999	9	8	55	25
1999	9	9	49	4

3 Key exceedance bins for Memphis are 21, 18, and 34. Other potentially important bins are 15 and 26.

Table 3-1b. SUMMARY of Maximum 8-Hour Ozone Concentration and Meteorological Regime for the 29 August–9 September 1999 Episode Days for Nashville.

Exceedances and key meteorological regimes (CART bins) are highlighted in bold.

Year	Month	Day	Maximum 8-Hour Ozone (ppb)	CART Bin[4]
1999	8	29	74	30
1999	8	30	65	10
1999	8	31	92	4
1999	9	1	100	11
1999	9	2	91	12
1999	9	3	91	25
1999	9	4	110	26
1999	9	5	109	26
1999	9	6	96	11
1999	9	7	79	13
1999	9	8	89	25
1999	9	9	60	30

Table 3-1c. Summary of Maximum 8-Hour Ozone and Meteorological Regime for the 29 August–9 September 1999 Episode Days for Knoxville.

Exceedances and key meteorological regimes (CART bins) are highlighted in bold.

Year	Month	Day	Maximum 8-Hour Ozone (ppb)	CART Bin5
1999	8	29	84	36
1999	8	30	82	20
1999	8	31	90	22
1999	9	1	105	32
1999	9	2	104	32
1999	9	3	101	33
1999	9	4	107	32
1999	9	5	90	35
1999	9	6	86	32
1999	9	7	102	21
1999	9	8	98	32
1999	9	9	86	28

[4] Key exceedance bins for Nashville are 11, 26, 16, and 28. Other potentially important bins are 23, 19, and 22.

[5] Key exceedance bins for Knoxville are 32, 21, and 15. Other potentially important bins include 37, 27, 36, 19, and 33.

The representativeness of these days for each of the three primary areas of interest is summarized in Table 3-2—first with respect to the 1997-1999 design values (Table 3-2a) and then with respect to the 1998-2000 design values (Table 3-2b). Days with maximum concentrations within 10 ppb of the design value are marked with a single asterisk. Of these days, those within a key meteorological regime are given a second asterisk.

Table 3-2a. Summary of Representativeness of Recommended Simulation Periods 8-Hour Ozone for Memphis, Nashville, and Knoxville.

Concentrations within approximately 10 ppb of the regional design values was based on the 1997-1999 design values of 95, 102 and 105 ppb for Memphis, Nashville, and Knoxville, respectively.

Year	Month	Day	Memphis	Nashville	Knoxville
1999	8	29			
1999	8	30			
1999	8	31	*	*	
1999	9	1	**	**	**
1999	9	2	**	*	**
1999	9	3	**	*	*
1999	9	4	*	**	**
1999	9	5		**	
1999	9	6		**	
1999	9	7	*		**
1999	9	8			**
1999	9	9			

Table 3-2b. Summary of Representativeness of Recommended Simulation Periods 8-Hour Ozone for Memphis, Nashville, and Knoxville.

Concentrations within 10 ppb of the regional design values was based on the 1998-2000 design values of 97, 102, and 102 ppb for Memphis, Nashville, and Knoxville, respectively.

Year	Month	Day	Memphis	Nashville	Knoxville
1999	8	29			
1999	8	30			
1999	8	31	*	*	
1999	9	1	**	**	**
1999	9	2	**	*	**
1999	9	3	**	*	*
1999	9	4	*	**	**
1999	9	5		**	
1999	9	6		**	
1999	9	7	*		**
1999	9	8			**
1999	9	9			

The 29 August–9 September 1999 includes:

- six 8-hour exceedance days, six days within approximately 10 ppb of the 1997-1999 design value, six days within 10 ppb of the 1998-2000 design value, and three of three key meteorological regimes (plus two other regimes) for Memphis
- eight 8-hour exceedance days, seven days within approximately 10 ppb of the 1997-1999 design value, seven days within 10 ppb of the 1998-2000 design value, and two of four key regimes (plus three other regimes) for Nashville
- ten 8-hour exceedance days, six days within approximately 10 ppb of the 1997-1999 design value, six days within 10 ppb of the 1998-2000 design value, and two of three key regimes (plus four other regimes) for Knoxville

Results—Additional ATMOS/EAC Episode

This section summarizes the results for selecting a modeling episode period to complement the original ATMOS episode and to support Early Action Compact (EAC) modeling for several areas within Tennessee and adjacent areas in Arkansas and Mississippi. The methodology used to identify new candidate episodes is the same as that used for the original ATMOS episode selection discussed above. It includes the use of Classification and Regression Tree (CART) analysis to classify days according to meteorological and air quality conditions, and the use of an objective optimization scheme (EPISODES) for selecting periods to represent key meteorological conditions and 8-hour ozone design values for multiple geographic areas. In applying CART, we used meteorological and ozone data for the period 1996 through 2003. Our analysis focused on the Memphis, Nashville, Knoxville, and Chattanooga areas. As a second step in the analysis we added Little Rock and Tupelo to the selection process. As a final step we reviewed the ozone concentrations for each candidate episode for Haywood, Lawrence, Meigs, Putnam, and the Tri-Cities counties in Tennessee. All candidate episodes were reviewed with respect to how well they complement the current ATMOS 1999 simulation period in achieving the episode selection objectives.

Primary Candidate Episodes

Of the candidates chosen by the EPISODES algorithm, the following episodes were favored for representing additional key meteorological regimes for the areas of interest, months different than those in the original 1999 episode, and more recent years: July 23 - 30, 2000, June 16 - 22, 2001, and July 5 - 10, 2002. Start-up and clean-out days are listed, but not considered in the analysis. Characteristics of the episodes are summarized in Table 3-3 below.

First we present the 1999 episode, and then each of the candidate episodes combined with the 1999 episode. “Key bins represented” refers to frequently occurring meteorological conditions or regimes that result in ozone exceedances. This is followed by a summary of ozone concentrations in the other areas of interest throughout Tennessee and a discussion of the attributes and limitations of the three candidate episode periods.

Table 3-3a. Original ATMOS Episode, August 29–September 9, 1999.

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	95.0	100.7	95.7	95.8	94.1	NA
Range of exceedances	86–106 ppb	90–110 ppb	86–104 ppb	88–107 ppb	85–98 ppb	NA
Exceedance days	6	8	8	6	4	0[6]
Days with 50% sites within 10ppb of DV	4	6	4	7	4	2
Key bins represented:	2 / 3	2 /5	3 / 5	2 / 3	1 / 2	0 / 3

Table 3-3b. July 23–30, 2000 Combined with August 29–September 9, 1999.

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	95.3	97.8	97.3	94.3	94.1	105
Range of exceedances	86–106 ppb	87–110 ppb	86–104 ppb	85–107 ppb	85–98 ppb	105 ppb
Exceedance days	9	11	11	7	4	1
Days with 50% sites within 10 ppb of DV	7	10	4	9	7	5
Key bins represented:	2 / 3	3 / 5	4 / 5	2 / 3	1/2	0 / 3

Table 3-3c. June 16–22, 2001 Combined with August 29–September 9, 1999.

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	94.4	99.9	97.6	95.4	94.1	86.7
Range of exceedances	86–106 ppb	90–110 ppb	86–104 ppb	88–107 ppb	85–98 ppb	86–87 ppb
Exceedance days	8	10	12	8	4	2
Days with 50% sites within 10 ppb of DV	7	8	8	10	6	5
Key bins represented:	2 /3	3 / 5	4 / 5	2 / 3	1 / 2	2 / 3

[6] Note that the 1999 episode includes one exceedance day for Little Rock, but this is a start-up day.

Table 3-3d. July 5–10, 2002 Combined with August 29–September 9, 1999.

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	94.8	99.8	95.5	93.9	94.1	89.6
Range of exceedances	86–106 ppb	90–110 ppb	86–104 ppb	85–107 ppb	85–98 ppb	86–91 ppb
Exceedance days	8	9	11	8	4	3
Days with 50% sites within 10 ppb of DV	7	7	6	9	5	5
Key bins represented:	2 / 3	3 / 5	3 / 5	2 / 3	1 / 2	2 / 3

Table 3-3e. Occurrence of Exceedances in Other Areas of Interest within Tennessee for Each Candidate Episode.[7]

Episode	Days with exceedances for at least 2 other TN areas	Days with at least 3 other TN areas within 10 ppb of DV	# of areas with at least one (near) exceedance day
July 23–30, 2000	0	1	1
June 16–22, 2001	2	2	2
July 5–10, 2002	2	2	4

July 23–30, 2000

This episode adds exceedances days for the Tennessee areas and important key bins for Nashville and Knoxville. However, the episode's ability to represent the Knoxville area is called into question by the fact that no days have at least half the sites near design value. A closer look at the original site data reveals that the Knoxville area maximums on these days are driven by high ozone at only one or two of the seven Knoxville sites. While this episode does a little bit better at representing Tupelo (there is a near-exceedance day that represents an additional key bin), it does not appear to be good for representing Little Rock. These days are also not characterized by high ozone within many of the other Tennessee areas of interest.

June 16–22, 2001

This candidate episode does fairly well at representing all areas of interest. Nashville and Knoxville each obtain a new key bin, and Little Rock gains two. Although no new key bins are added for Memphis or Chattanooga, for these areas the episode provides more days from key bins already included in the 1999 episode. Of the primary candidates, this episode provides the most new key bins. In general, the episode is characterized by exceedances in all ATMOS areas except Tupelo, and in two of the non-ATMOS (other Tennessee) areas, as well as

7 The "other TN areas" considered in here are Haywood County, Lawrence County, Meigs County, Putnam, and the Tri-Cities area. The July 2000 episode seems only to reach Meigs County. The June 2001 ozone episode affects Meigs County and the Tri-Cities area. The July 2002 dates seem to capture a widespread ozone episode, with exceedances in Haywood, Meigs County, Putnam, and the Tri-Cities area. No exceedance days are found in Lawrence County during these episodes, although all three episodes have days where the Lawrence County site is within 10 ppb of its design value.

multiple sites near the design value for all ATMOS areas and sites near design value for three non-ATMOS areas.

July 5–10, 2002

This candidate stands out as being the best episode for Little Rock, with all three of its days in new key Little Rock bins and with both Little Rock sites within 10 ppb of their design value for each of these days. The episode is also characterized by widespread exceedances in non-ATMOS areas of Tennessee. However, for the four principal ATMOS/Tennessee areas of interest, it adds only one new key bin (for Nashville). In terms of achieving days with multiple sites near the site-specific design value, this episode is somewhat weaker than the June 2001 episode in representing Nashville, Knoxville, Chattanooga, and Tupelo.

Other Episodes

The episode selection algorithm also selected an August 2000 and an August 2002 episode, both of which are worth some consideration. The information tabulated for the June and July episodes above is done so for the August episodes in Table 3-4 below.

These episodes are good to excellent by some measures, for some areas, but in other ways comparable to or not as good as the June 2001 episode. The June and July episodes have the advantage of adding greater variety in terms of time of year.

Table 3-4a. August 12–18, 2000 with August 29–September 9, 1999

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	95.1	98.8	97.8	97.3	93.5	90.7
Range of exceedances	86–107 ppb	89–110 ppb	86–104 ppb	88–107 ppb	85–98 ppb	89–91 ppb
Exceedance days	9	11	11	8	5	2
Days with 50% sites within 10 ppb of DV	7	9	6	8	7	5
Key bins represented:	2 / 3	2 / 5	4 / 5	2 / 3	1 / 2	0 / 3

Table 3-4b. August 6–14, 2002 with August 29–September 9, 1999

Metric	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
2000–2002 DV	94	88	98	93	81	86
Mean exceedance val.	93.9	98.8	98.9	93.7	94.1	86.8
Range of exceedances	86–107 ppb	85–110 ppb	83–109 ppb	85–112 ppb	85–98 ppb	86 ppb
Exceedance days	8	12	14	11	4	1
Days with 50% sites within 10 ppb of DV	4	9	10	12	5	4
Key bins represented:	2 /3	4 / 5	4 / 5	3 / 3	1 / 2	1 / 3

Table 3-4b. Occurrence of Exceedances in Other Areas of Interest within Tennessee, for Above Episodes.

Episode	Days with exceedances for at least 2 other TN areas[8]	Days with at least 3 other TN areas within 10 ppb of DV	# of areas with at least one (near) exceedance day
August 12–18, 2000	2	2	3
August 6–14, 2002	6	6	4

August 12–18, 2000

This candidate episode adds one or more exceedance days for all of the primary areas of interest, with the exception of Tupelo. Additional key meteorological regimes are added for the Knoxville area.

August 6–14, 2002

This candidate episode does fairly well at representing all areas of interest. Key bins are added for Nashville, Knoxville, Chattanooga, and Little Rock. Some additional bins are also added for Memphis, although these are not among the most frequently occurring exceedance regimes. Overall, the episode provides the most new key bins. In general, the episode is characterized by exceedances in all ATMOS areas except Tupelo, and in four of the non-ATMOS (other Tennessee) areas. The values for Meigs, Putnam, Blount, and Kings Counties are high relative to the design values for these areas.

[8] "Other TN areas" defined in Table 3-3e above.

Final Episode Selection

The following tables summarize the candidate episodes in terms of the number of exceedance days and representation of additional (to the 1999 episode) key meteorological regimes.

Table 3-5. Number of 8-Hour Ozone Exceedance Days for Each Candidate Episode Period.

Episode	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
August/September 1999	6	8	8	6	4	0
July 2000	3	3	3	1	0	1
August 2000	3	3	3	2	1	2
June 2001	2	2	4	2	0	2
July 2002	2	1	3	2	0	3
August 2002	2	4	6	5	0	1

Table 3-6. Original Count and Number of Additional, Distinct Key Meteorological Bins (Regimes) for Exceedance (or Near-Exceedance) Days for Each Candidate Episode Period.

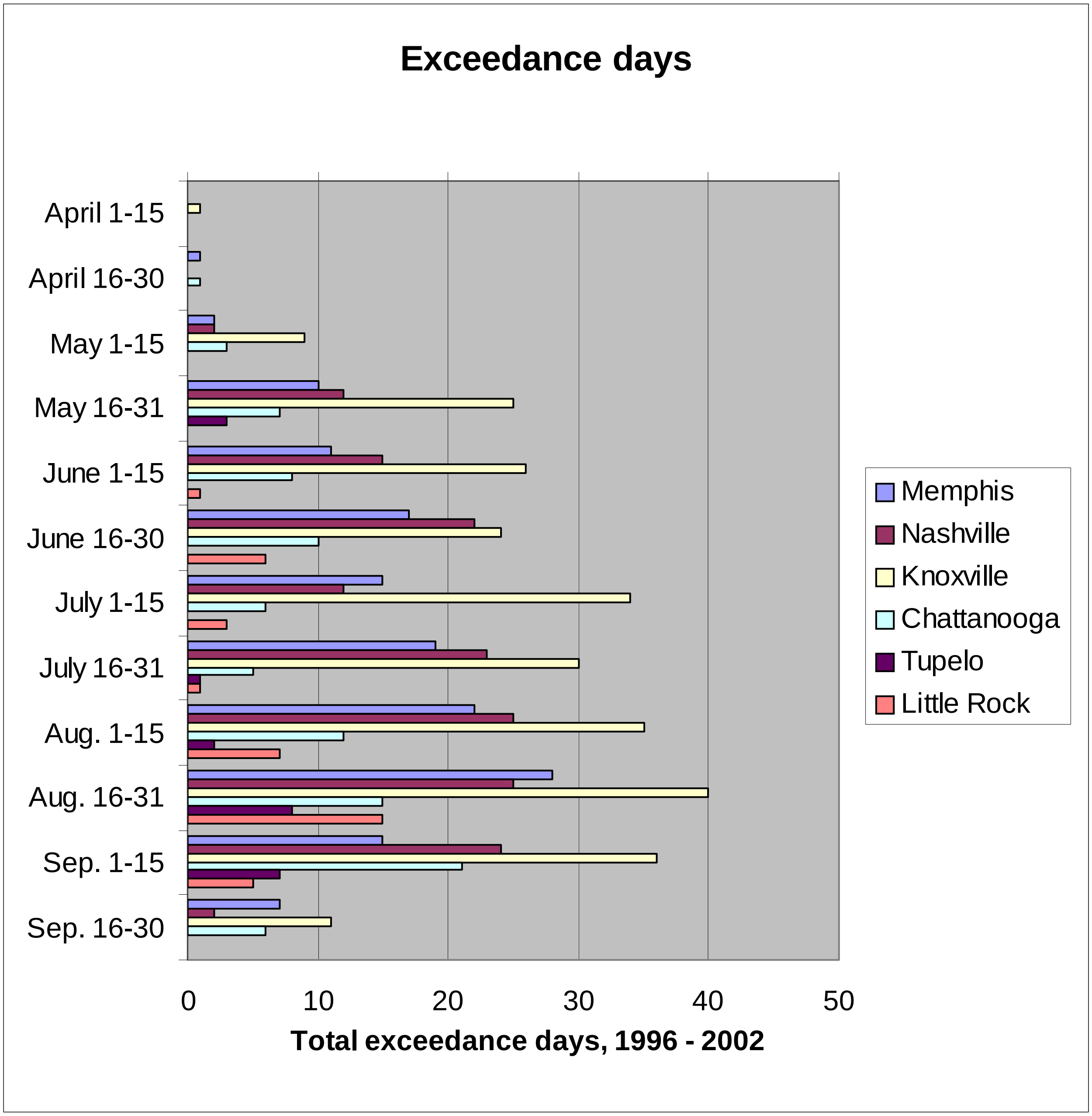
Episode	Memphis	Nashville	Knoxville	Chattanooga	Tupelo	Little Rock
August/September 1999	2/3	2/5	3/5	2/3	1/2	0/3
July 2000	0	1	1	0	0	0
August 2000	0	0	1	0	0	0
June 2001	0	1	1	0	0	2
July 2002	0	1	0	0	0	2
August 2002	0	2	1	1	0	1

Based on a discussion with the ATMOS Operations Committee, the episode selected for the EAC modeling is June 16-22, 2001. When combined with the August/September 1999 simulation period, this episode provides 8 to 12 exceedance days for the four key Tennessee areas of interest, two exceedance days for Little Rock, and four exceedance days for Tupelo. The two episodes combined also provide between two and eight exceedance days for the other Tennessee areas of interest.

The June 2001 episode provides for representation of an important key bin (meteorological regime) for Nashville that is not accounted for in the original ATMOS episode, as well as for further representation of a key bin already represented by the 1999 ATMOS episode. For Knoxville, the June 2001 exceedance days represent one new key bin, two already represented key bins, and one additional bin. For Memphis, the June 2001 exceedance days represent one already represented key bin (the largest bin), and one additional bin that is a neighbor to the key bin that is not represented and is thus likely similar in its features. For Chattanooga, the June 2001 exceedance days represent the key bin for that area. Finally, two of the three key bins for Little Rock are represented by exceedance days.

The June 2001 episode is more seasonally different from the August/September 1999 episode, although both episodes represent key periods during which ozone exceedances tend to occur, as illustrated in Figure 3-1 below.

Figure 3-1. Distribution of Exceedance Days, 1995–2002.



4. Photochemical and Meteorological Modeling Domain Specification

The modeling domain for application of the UAM-V was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the area of interest. The modeling domain to be used in the EAC modeling analysis is the same as what has been used for the ATMOS modeling. The UAM-V modeling domain is presented in Figure 4-1 and includes a 36-km resolution outer grid encompassing the southeastern U.S; a 12-km resolution intermediate grid; and a 4-km resolution inner grid encompassing Tennessee and portions of Mississippi, Arkansas, and other neighboring states.

The regional extent of the modeling domain is intended to provide realistic boundary conditions for the primary areas of interest and thus avoid some of the uncertainty introduced in the modeling results through the incomplete and sometimes arbitrary specification of boundary conditions. The use of 4-km grid resolution over the primary area of interest is consistent with an urban-scale analysis of each of the areas of interest.

The UAM-V domain is further defined by eleven vertical layers with layer interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters (m) above ground level (agl). Further testing of the appropriateness of the vertical grid structure may be performed as part of the diagnostic testing, as described in Section 7 of this protocol document.

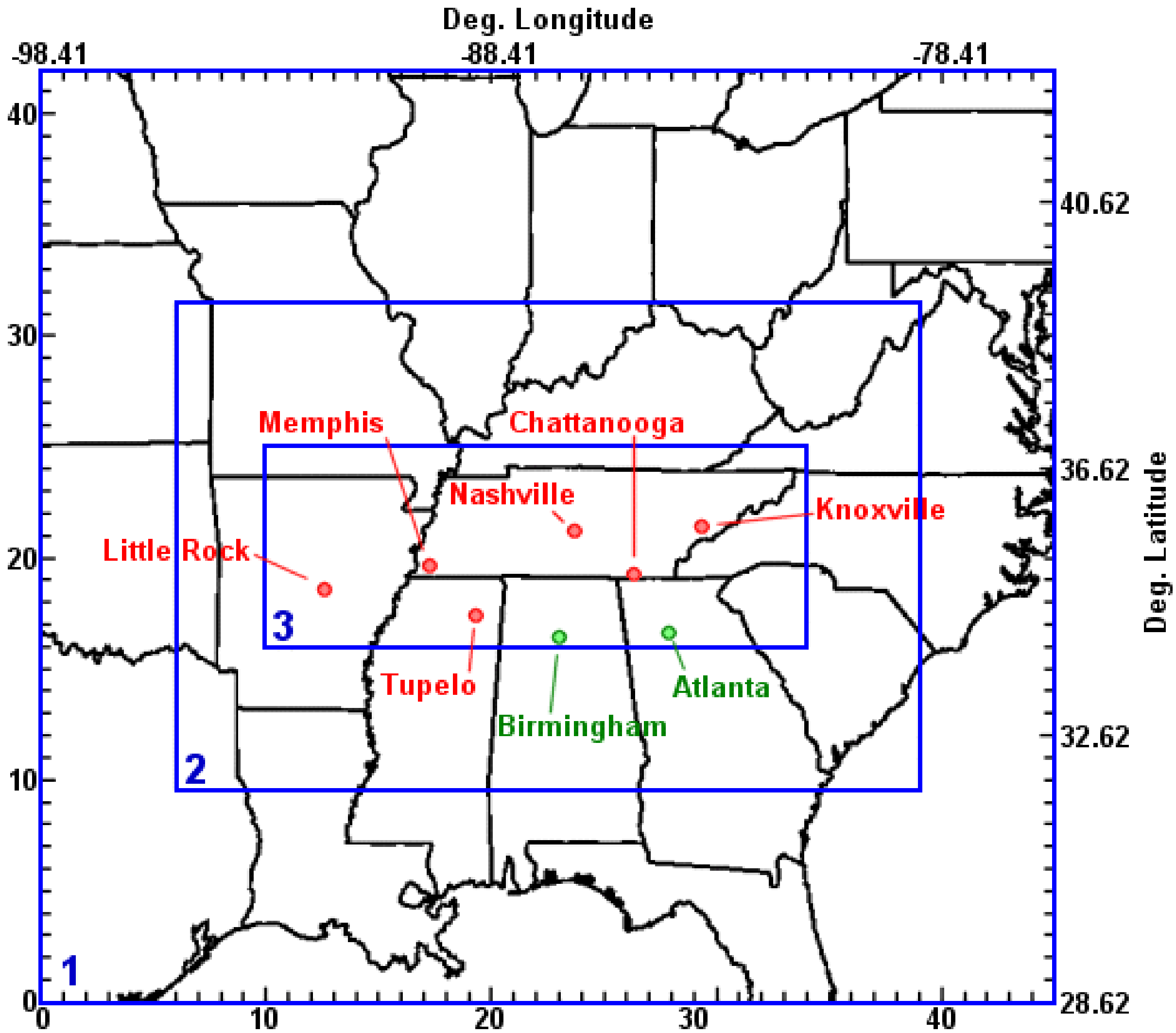
The modeling domain for application of MM5 is shown in Figure 4-2. This domain is much larger than that for UAM-V, in order to enable the simulation of any important synoptic scale features and their influence on the regional meteorology. The modeling domain consists of an extended outer grid with approximately 108-km horizontal resolution and four inner (nested) grids with approximately 36, 12, and 4-km resolution. The horizontal resolution was specified to match that for UAM-V. A one-way nesting procedure and 22 vertical levels will be employed. The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights for application of MM5 are listed in Table 4-1.

Table 4-1. MM5 vertical levels for the ATMOS application.

Level	Sigma	Average Height[9] (m)
1	0.996	30
2	0.988	80
3	0.982	125
4	0.972	215
5	0.960	305
6	0.944	430
7	0.928	560
8	0.910	700
9	0.890	865
10	0.860	1115
11	0.830	1370
12	0.790	1720
13	0.745	2130
14	0.690	2660
15	0.620	3375
16	0.540	4260
17	0.460	5240
18	0.380	6225
19	0.300	7585
20	0.220	9035
21	0.140	10790
22	0.050	13355

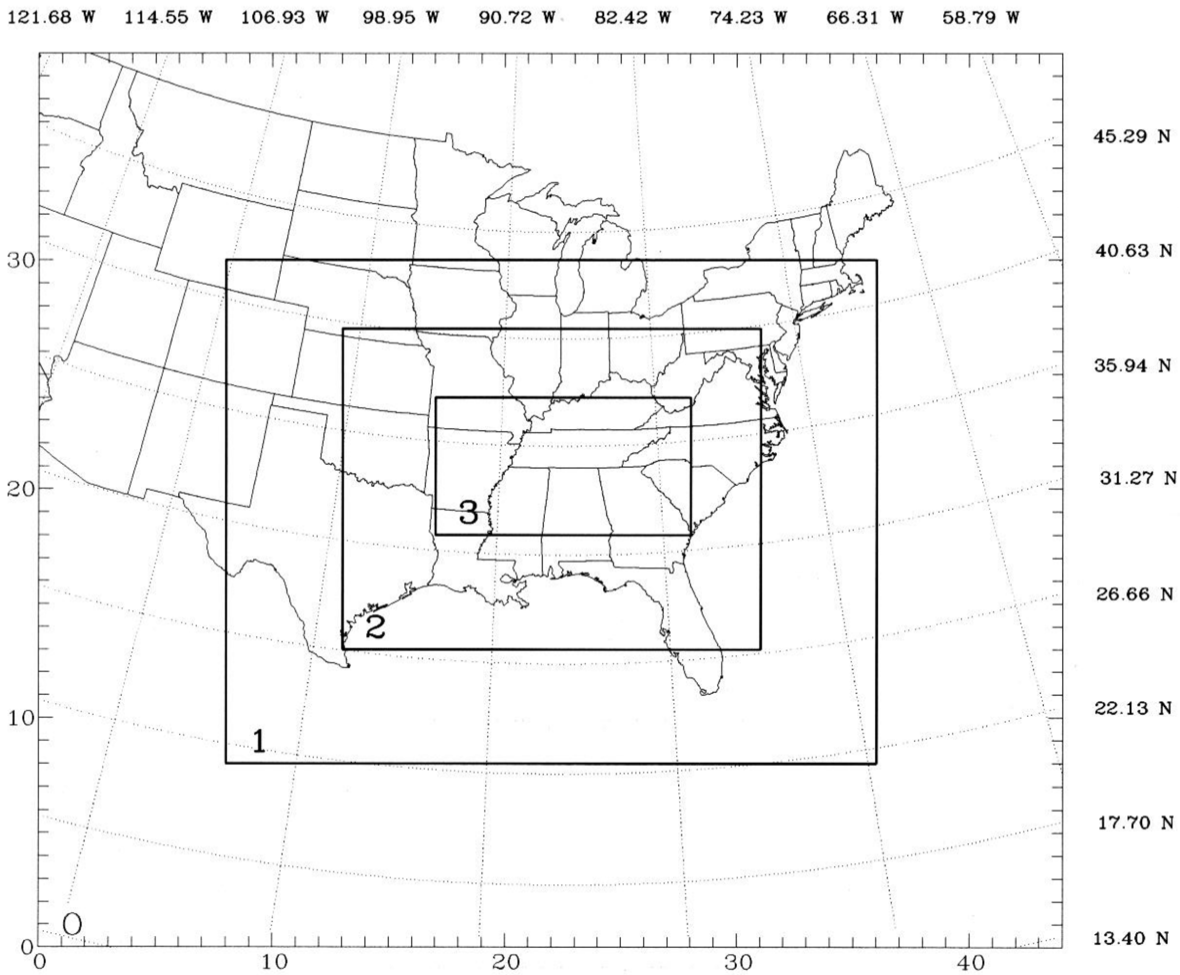
9 Approximate heights—to be updated following initial application of MM5.

Figure 4-1. UAM-V modeling domain for the ATMOS study.



Grid 1: (-98.41,28.62)—45x42—36-km Cells
Grid 2: (-95.41,31.79)—99X66—12-Km Cells
Grid 3: (-93.41,33.96)—215x81—4-km Cells

Figure 4-2. MM5 modeling domain for the ATMOS application.



MM5 Grid Configuration for ATMOS. Central lat & lon (34.10, −87.40)

0: (0, 0) 44 x 39 – 108km Cells
1: (8, 8) 85 x 67 – 36km Cells
2: (13,13) 163 x 127 – 12km Cells
3: (17,18) 163 x 298 – 4km Cells

5. Input Preparation

Version 1.5 of the UAM-V modeling system will be used for the ATMOS modeling analysis. This latest version of the model includes the Carbon Bond 5 chemical mechanism, accommodates the use of a variety of horizontal coordinate systems, and provides for the use of either the standard or enhanced ("fast") chemistry solver. It also includes process analysis and oxidant tagging capabilities.

The UAM-V modeling system requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, day-specific emissions estimates and meteorological fields; initial and boundary conditions; land-use information; and chemistry parameters. The methods and data to be used in preparing the UAM-V inputs for the ATMOS/EAC base-case modeling exercises are described in this section of the protocol document.

Base-Year Emission Inventory Preparation

The UAM-V requires specification of gridded low-level emissions for the full domain and each subdomain. Elevated point source emissions for all sources within the domain are contained in a single input file. The preparation of these input files is described in this section.

Emission Inventory Requirements for Modeling

In order for photochemical simulation models to adequately simulate temporal and spatial variations in ozone concentrations, the emission inventories input to these models must contain considerably more detail than an inventory generated to meet periodic emission inventory reporting requirements. The primary additional requirements of the photochemical modeling inventory are summarized below. This information is primarily derived from the EPA guidance document entitled *Procedures for the Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Volume II: Emission Inventory Requirements for Photochemical Air Quality Simulation Models*, prepared by SAI (EPA, 1992b).

Spatial Allocation: Emission estimates of precursor pollutants must be provided for each individual cell of a grid system within the modeling domain instead of at a county or regional level.

Temporal Allocation: Emissions must be specified as hourly rather than annual or daily rates. Additionally, annual or seasonal average rates should be adjusted to reflect episodic or day-specific conditions as accurately as possible.

Chemical Speciation: Total reactive VOC and NO_x emissions estimates must be disaggregated into several classes of VOC and NO and NO_2, respectively; spatially and temporally resolved emission estimates of CO may also be required (EPA requires that CO emissions be input to the UAM-V in ozone attainment demonstrations).

Stack Parameters: For models such as the UAM-V that provide for vertical resolution of pollutants, stack and exhaust gas parameters must be provided for each large point source.

Each of these is discussed further below.

Spatial Allocation of Emissions

Point Sources. Point source locations are typically reported to within a fraction of a kilometer; hence, assigning emissions from these sources to the appropriate grid cell is simple.

Area Sources. By contrast, spatial resolution of area source emissions requires substantially more effort. Two basic methods can be used to apportion area source emissions to grid cells. The most accurate (and resource-intensive) approach is to obtain area source activity level information directly for each grid cell. The alternative approach, more commonly employed, is to apportion the county-level emissions from the existing annual inventory to grid cells using representative apportioning factors for each source type.

This latter approach requires the determination of apportioning factors based on the distribution of some spatial surrogate indicator of emission levels or activity (e.g., population, census tract data, or type of land use) for each grid cell. These factors are then applied to the county- or parish-level emissions to yield estimates of emissions from that source category by grid cell. The major assumption underlying this method is that emissions from each area source category behave spatially in the same manner as the spatial surrogate indicator. In most large urban areas, local planning agencies can provide detailed land use, population, or in some cases, employment statistics at the sub-county level. These data can be used to spatially apportion most of the area source emissions in the modeling inventory.

A spatial surrogate indicator is a parameter with a known distribution at a sub-county level and a behavior that is similar to the activity levels of interest. Commonly used spatial surrogate indicators include land-use parameters, employment in various industrial and commercial sectors, population, and dwelling units. Different surrogate indicators can be used to apportion emissions for the various area source categories, of course, depending on which of the available indicators best describes the spatial distribution of the emissions.

Mobile Sources. Planning, land-use, and transportation models are already in use in many urban areas, and can provide much of the data necessary to allocate mobile source emissions and develop emission estimates by link for highway motor vehicles. Such models are also generally capable of developing forecasts for future years which can be utilized in the development of projection inventories.

Mobile sources differ from stationary source categories in that their spatial variation is more accurately described using a link-based rather than a surrogate-based gridding procedure. In a link-based spatial allocation approach, emissions are distributed only to those grid cells that contain transportation pathways (e.g., roadways, railways, airports, shipping channels, etc.). This approach is usually used in conjunction with a surrogate-based procedure to complete the spatial resolution of the mobile source inventory.

Emissions from on-road vehicles on limited access roadways (interstates and expressways), railroad locomotives, aircraft, and vessels are often spatially allocated with a link-based procedure, since the transport routes used by these vehicles are both easily identifiable and readily modeled as a series of lines or links. This results in more accurate allocation of emissions from these sources than could be achieved using surrogates such as population or land use.

Non-link surrogates are commonly used to spatially allocate mobile emissions in the following situations:

- Links are too numerous to define and process, as is typically the case for on-road rural and urban vehicles and for off-road vehicles.
- Emission totals are too insignificant when compared with emissions from other sources in the modeling domain to warrant the development of link data.
- Use of gridded spatial surrogates based on land-use or population data provides a more accurate allocation of vehicle emissions. For example, recreational boating activities may be distributed approximately equally over the surface of a large lake.

In most modeling applications, a combination of link and land-use surrogates is used for the spatial allocation of mobile source emissions.

Temporal Resolution of Emissions

In order to simulate hourly concentrations of ozone and other pollutants, photochemical models require hour-by-hour estimates of emissions at the grid cell level. Several approaches can be used to provide the temporal detail needed in the modeling inventory. The most accurate and exacting approach is to determine the emissions (or activity levels) for specific sources for each hour of a typical day in the time period being modeled.

As an alternative, typical hourly patterns of activity levels can be developed for each source category. These are then applied to the annual or seasonally adjusted emissions to estimate hourly emissions. This approach is commonly employed for area sources, including highway motor vehicles, and is usually used for all but the largest point sources.

Usually, the photochemical air quality model is applied for an episode in the season of the year in which meteorological conditions are most conducive to ozone formation; for most locations, this means the summer months (i.e., May through September). Consequently, emissions must be adjusted to reflect typical levels for the appropriate season.

Similarly, emissions must also be adjusted to reflect whether the simulation day is a weekday or a weekend day. For simulation periods that include both weekday and weekend days, temporal pattern information pertaining to both weekday and weekend days is required.

Point Sources. The modeling inventory should represent as accurately as possible day-specific emission estimates for each hour of the modeling episode. By contrast, the existing point source inventory will more likely contain annual or typical ozone season day estimates of emissions and a general description of the operating schedule (seasonal fractions of annual throughput, and operating schedule in terms of weeks/year, days/week, and hours/day in operation).

Ideally, each facility would be contacted to obtain hourly operating records for the modeling episode, or, if this information is unavailable, representative operating schedules for a typical ozone season day. Certain local agencies may also have this type of temporal information. Some sources for which this type of data may be available include the following: power plants (which generally keep detailed, hourly records of fuel firing rates and power output for each day of operation), major industrial facilities such as automotive assembly plants and refineries, and tank farms.

For many smaller point sources, reasonable temporal resolution can be obtained from the operating data that are typically collected for each point source.

Area Sources. Since the basic area source inventory usually contains estimates of annual (or sometimes seasonally adjusted) emissions, the emissions modeler must expend additional effort to estimate hour-by-hour emission rates for the episode days. Several approaches can be employed to develop hourly emissions resolution; all involve the use of assumed diurnal patterns of activity. In addition to hourly patterns, estimates of seasonal fractions of annual activity will be needed if the county-level inventory is not seasonally adjusted. Activity profiles by day of week will also be required.

Mobile Sources. Temporal adjustment of the mobile source inventory into monthly, daily, and hourly specific totals is not significantly different than the treatment of other area source categories. If hourly vehicular speeds and VMT distributions are available from the local Metropolitan Planning Organizations (MPOs), these can be utilized in estimating hourly mobile source emissions.

Chemical Resolution of Emissions

Because photochemical models like the UAM-V are intended to simulate photochemistry, they require specific information as to the proportions of the various types of VOC emissions present in the inventory. For this reason, VOC emission totals must be disaggregated into subtotals for various chemical classes. NO_x emissions also have to be distributed as NO and NO_2. Literally thousands of individual chemical compounds typically compose the total VOC emissions in an urban area. No photochemical model considers each organic compound individually; instead, VOC emissions are distributed into chemical classes which behave similarly in photochemical reactions. The UAM-V employs a carbon-bond classification scheme based on the presence of certain types of carbon bonds in each VOC molecule. The latest version of this mechanism is CB-V.

Two basic approaches can be followed for determining split factors. Ideally, VOC split factors should be source-specific, reflecting the actual composition of VOC emissions from each individual source.

In some instances, source-specific VOC species data may be available for certain individual facilities (perhaps through source tests or material composition considerations). Generally, however, most industries cannot provide reliable VOC or NO_x species data or accurately apportion their emissions into appropriate classes, in which case generalized VOC and NO_x distributions must be assumed for various source categories.

Because of resource limitations and unavailability of solvent composition data, however, collecting source-specific speciation data is generally impractical for all but a very few large point or area source emitters. An alternative method employs generalized VOC speciation data from the literature to develop VOC split factors by source type.

Elevated Point Source Requirements

The emission inventory must include stack information (e.g., physical stack height and diameter, stack gas velocity, and temperature) for the major point sources in the area. All point sources with an effective stack height (i.e., the sum of the physical height of the stack and any plume rise) greater than 25 meters is considered to be an elevated point source. The emissions from elevated point sources are assigned to the grid cells based on location of the stack and effective plume rise.

Emissions Data

The ATMOS EAC modeling inventory will be based primarily on the Version 2 of EPA's 1999 National Emissions Inventory (NEI-99), and will follow procedures similar those followed in preparing emissions for the original ATMOS episode. To ensure the most accurate estimation of base-year ozone precursor emissions for the AR-TN-MS area possible, we will also obtain the latest information available for each of these states and incorporate these data into the modeling inventory as permitted by schedule and resource limitations. Specifically, the following information will be solicited from each of these states:

- Area source data (county/parish level emission estimates, population, and activity information)
- Point source data (stack parameters, emission rates, etc.)
- Mobile source data (VMT, speeds, fleet mix, fuel characteristics, program characteristics, etc.)

An updated mobile source inventory for the State of Tennessee, prepared by the University of Tennessee's Center for Transportation Research, will be used.

Episode-Specific Information

To further refine the base-year inventories, it is desirable to refine the annual inventory to incorporate known differences for the specific episode being simulated. For example, if a particular large point source was not operating during the episode, this information should be incorporated in the episode-specific inventory. Emission estimates should also be adjusted to reflect seasonal conditions. We will thus obtain any available episode-specific and/or seasonal information that would affect any portions of the inventory for the episode.

For each episode to be modeled, the types of information needed include the following:

- Daily (or preferably hourly, if available) emissions data for major point sources for each of the episode days. If significant differences in associated stack parameters such as temperature, flow rate, and velocity are documented, these data can be used as well.
- List of sources not in operation for each episode day.

Emissions Processing Tools and Procedures

To facilitate development of the detailed emission inventories required for photochemical modeling for this analysis, a version of the EPA UAM Emissions Preprocessor System (EPS 2.5) will be used. This system, developed by SAI under the sponsorship of the EPA's Office of Air Quality Planning and Standards, consists of a series of computer programs designed to perform the intensive data manipulations necessary to adapt a county-level annual or seasonal emission inventory for modeling use. EPS 2.5 provides the capabilities to support the CAAA requirements, to conform to EPA emission inventory requirements, and to allow the evaluation of proposed control measures for meeting Reasonable Further Progress (RFP) regulations and special study concerns.

In addition, the latest available version of EPA's Biogenic Emissions Inventory System (BEIS) will be used to estimate day-specific biogenic emissions for the modeling analysis. Currently, this is BEIS-2, but BEIS-3 will be used if it is available in version that can be used in this modeling analysis. County-level biomass estimates are provided as part of the BEIS input data package. Temperature and solar radiation estimates will be extracted from the output of the MM5 meteorological model.

EPA's MOBILE model will be used to provide estimates of motor vehicle emissions. The current operational version of this model is MOBILE6.2. The MOBILE model will be applied at the county level, using county level estimates of vehicle miles traveled (VMT). The VMT will be distributed temporally using a weekly profile as presented in Table 5-1. These values are based on more recent national average traffic count information (collected in the 1990s).

Table 5-1. Proposed Weekly Profile for On-Road Motor Vehicles.

Day of Week	Fraction of Average Daily Emissions
Sunday	0.84
Monday	1.01
Tuesday	1.03
Wednesday	1.02
Thursday	1.04
Friday	1.11
Saturday	0.96

In addition to the temporal adjustment, MOBILE will be used along with the MM5-derived gridded surface temperature fields to adjust the emission estimates to reflect ambient conditions for each hour of the simulation.

The latest version of EPA's NONROAD model (NONROAD 2002) will also be used to estimate nonroad emissions throughout the domain.

The core EPS 2.5 system consists of a series of FORTRAN modules that incorporate spatial, temporal, and chemical resolution into an emissions inventory used for photochemical modeling. EPS 2.5 system input files which must be created specific to each modeling region include: (1) projection factors used to forecast or back-cast emission rates from the year of input emissions to the episode modeling year, (2) gridded area, population, and land use surrogates used to spatially allocate area source emissions, and (3) digitized link data used to spatially allocate selected source categories (routinely mobile sources). Point, area, and mobile source emission data are usually processed separately through the EPS 2.5 system to facilitate both data tracking for quality control and the use of the data in evaluating the effects of alternative proposed control strategies on predicted air pollutant concentrations.

Point source data are initially processed by the PREPNT module, which performs an initial screening of the data to determine whether each source will be treated as low-level or elevated. PREPNT also converts the input data to the EPS 2.5 internal Emission Model Binary Record

(EMBR) format. The point source inventory is then ready for projection to future year levels, temporal allocation, and chemical speciation.

County-level (or other aggregated) area and mobile source emissions data enter the EPS 2.5 system through the PREAM module, which separates the area and on-road motor vehicle emissions data into two files. (If data for calculating link-based mobile source emissions are available, the LBASE module serves as the entry point for these data.) The emissions files created by PREAM are in the EMBR format. The PREAM module also disaggregates total motor vehicle emissions, which are usually reported in the input data by road type (limited access, urban, suburban, and rural) and vehicle class (light-duty gasoline vehicles, light-duty gasoline trucks, heavy-duty gasoline vehicle, and heavy-duty diesel vehicle), into the four emission component categories employed by EPA's MOBILE models (versions 4.0 and higher): exhaust, evaporative, refueling losses, and running losses. The on-road motor vehicle emissions are then adjusted to reflect episodic and scenario-specific conditions, such as existing or proposed Inspection and Maintenance (I/M) programs, Stage II vapor recovery controls, and ambient temperatures.

Each of the inventory components (e.g., point sources, area sources, on-road motor vehicles) are then processed separately through the remaining modules of EPS 2.5 to facilitate quality control tracking and control strategy analysis. After projection to the year to be modeled (performed by the CNTLEM module), each file is chemically speciated and temporally allocated by the CHMSPL and TMPRL modules, respectively. For area sources, non-road mobile sources, and on-road motor vehicles, county-level emission totals by source category are spatially allocated to individual grid cells in the UAM-V modeling domain by the GRDEM module; point source emissions are allocated to grid cells based on source location. The GRDEM module has a user option specifying the desired format of the output emissions file, either gridded EMBR format or UAM-V low-level emissions file format. The gridded anthropogenic emissions files are then merged with the biogenic emissions file into a single low-level emissions file, as the final step prior to input to the UAM-V.

Selection of Sources for P-i-G Treatment

Point sources for plume-in-grid (P-i-G) treatment will be selected according to NO_x emission rate as follows:

- For Grid 3 (4 km high-resolution grid) - Impose P-i-G on all sources with facility totals > 5 tpd NOx, except for those individual sources within the facility that are < 1 tpd
- For Grids 1 and 2 (36 and 12-km resolution grids, respectively) - Impose P-i-G on all sources with facility totals > 10 tpd NOx, except for those individual sources within the facility that are < 2 tpd.

Quality Assurance of the Emissions Inputs

Obviously, the accuracy and representativeness of any UAM-V modeling inventory will be limited by the quality of the input emissions data. Although the EPS 2.5 modules do perform some basic validity checks upon data input to each module, verifying the accuracy of the original emissions data is not a function of the EPS 2.5 system. Consequently, appropriate quality assurance procedures must be performed on the input emissions data prior to processing through EPS 2.5. Our proposed approach to quality assurance of the emissions inventory, which addresses both of these concerns, accordingly distinguishes between two basic levels of quality assurance. The first regards the inherent quality of the data input to EPS 2.5; the second pertains to tracking the data through each step of processing.

We will review the base year inventory database used to develop the UAM-V modeling inventories, along with any available documentation, and assess the methodologies, assumptions, emission factors, and other parameters used to estimate emissions to the extent that this information is available from existing documentation or internally documented within the inventory database. The quality review process will follow the guidance set forth in *Quality Review Guidelines for 1990 Base Year Emission Inventories* (EPA-454/R-92-007, EPA, 1992c). This document describes a two-tiered approach to quality review; SAI will employ a similar procedure in reviewing the base year inventory for the ATMOS modeling domain. The first phase of this review will consist of an overall assessment of the inventory to ensure that the minimum data requirements and quality standards set forth in *Emission Inventory Requirements for Ozone State Implementation Plans* (EPA-450/4-91-010, March 1991) are met. The types of issues that will be addressed include the following:

- inclusion of all required components (i.e., point, area, on-road motor vehicles, biogenics)
- geographical coverage of the inventory (emission estimates should be provided for all counties in the modeling domain, not just the counties located in the actual nonattainment area)
- assessment of completeness of database (identification of default or missing values for inventory parameters such as source location, stack parameters, operating schedules, etc.)
- inclusion of existing regulatory requirements, including rule effectiveness and rule penetration factors for applicable sources and source categories.

The quality review process described above addresses the inherent quality of the data input to the EPS 2.5 system. The second phase of this effort will address the processing of the input inventory data to generate the base year UAM-V modeling inventory. To conduct this review, SAI will track the emissions data set through each stage of EPS 2.5 processing. SAI will verify that the specified input and output files for each processing step contain the appropriate information required to process the emissions data in the expected manner. Temporal profile assignments for each source category, including seasonal, weekly, and diurnal variations will be reviewed. The spatial allocation surrogate data and surrogate assignments for each source category will also be examined. SAI will ascertain that all required processing steps have been completed in an appropriate order and will track input and output emissions totals for each processing step to identify any gross errors in processing. For the future year modeling inventory, the review will focus on the control assumptions and projection factors used to estimate future year emission rates.

Each of the EPS 2.5 core modules and utilities produces a message output file containing summary information on the processed files, as well as errors or warning conditions encountered during execution. These messages can be broadly categorized into three types: (1) messages pertaining to unsuccessful input/output (I/O) operations (i.e., opening, reading, and writing data files), (2) messages notifying the user that internal EPS 2.5 maximum parameters (which are used to dimension internal data arrays) have been exceeded, and (3) messages indicating invalid or questionable input data. SAI will examine the message files produced at each stage of processing to identify any warning or error conditions and reprocess data as needed to alleviate these conditions.

SAI will also make use of the quality control and reporting modules provided with EPS 2.5 as well as in-house quality assurance tools (e.g., plotting programs for examining temporal variations and spatial distribution of gridded emissions) to further examine the modeling inventory.

Upon completion of the quality review, SAI will prepare a technical memorandum summarizing the data included in the base year inventory, focusing on sources of VOC and NO_x emissions.

To facilitate the quality assurance and review of the emissions inputs, the following tabular and graphical summaries will be prepared and examined:

- Plots illustrating the magnitude and spatial distribution of low-level emissions of VOC, NO_x, and CO (by component, total anthropogenic, and total anthropogenic and biogenic)
- Plots illustrating the magnitude and spatial distribution of elevated point-source emissions of VOC, NO_x, and CO
- Plots illustrating the temporal distribution of low-level emissions of VOC, NO_x, and CO (by component, total anthropogenic, and total anthropogenic and biogenic)
- Plots illustrating the temporal distribution of elevated point-source emissions of VOC, NO_x, and CO
- Tables summarizing emissions totals for VOC, NO_x, and CO (by component, total anthropogenic, and total anthropogenic and biogenic) for each UAM-V grid
- Tables summarizing emissions totals for VOC, NO_x, and CO (by component, total anthropogenic, and total anthropogenic and biogenic) for the potential nonattainment counties in the area of interest.

Meteorological Input Preparation

Meteorological Input Requirements

The UAM-V requires hourly, gridded inputs of wind, temperature, water-vapor concentration, pressure, vertical exchange coefficients (K_v), cloud-cover, and rainfall-rate. Meteorological inputs for this UAM-V application were prepared using the MM5 meteorological model. All meteorological inputs will be directly specified for UAM-V Grids 1, 2, and 3 (refer to Figure 4-1 for the grid definitions). This section summarizes the preparation of meteorological inputs using the MM5 modeling system.

Meteorological Data

Meteorological data for the application of MM5 will be obtain from NCAR and will include the National Center for Environmental Prediction (NCEP) global analysis and surface and upper air wind, temperature, moisture, and pressure data for all routine monitoring sites within the domain. These include National Weather Service (NWS) sites, buoys, and a few international monitoring sites. Sea-surface temperature data will also be obtained from NCAR. These data comprise the standard data set for application of the MM5 modeling system and will be used for data assimilation as well as for the evaluation of the modeling results. In addition to these data, surface and upper-air data for a small number of additional monitoring sites within the domain (representing special study or facility-specific monitoring sites) will also be obtained and used for model performance evaluation as well as in the diagnosis of model performance problems.

Meteorological Modeling Tools and Procedures

A general description of the MM5 meteorological model is found in Anthes and Warner (1978). The governing equations include the equations of motion, the continuity equations for mass and water vapor, and the thermodynamic equation. Those features relevant to this application are briefly described in this section.

The current version of MM5 can be applied in a non-hydrostatic mode for the improved simulation of small-scale vertical motions (such as those associated with the sea breeze and terrain effects). Use of this optional feature can be important to the accurate simulation of the airflow and other features at high horizontal resolution and will be utilized for this study.

The MM5 model employs the sigma vertical coordinate: $\sigma = (p—p_t)/(p_s—p_t)$, where p is pressure, p_t is the constant pressure specified as the top of the modeling domain, and p_s is the surface pressure. The sigma-coordinate surfaces follow the variable terrain. Twenty vertical levels will be employed for this application such that the greatest vertical resolution is obtained within the boundary layer. Information on the vertical structure of the MM5 modeling domain is given in Table 4-1.

The governing equations are integrated over a grid that is staggered in the horizontal and vertical (Messinger and Arakawa, 1976). In the horizontal, the u and v wind components are calculated at points that are staggered with respect to those for all other variables. In the vertical, vertical velocity is defined at the sigma levels while all other variables are defined at intermediate sigma levels.

The MM5 modeling system also supports the use of multiple nested grids. This feature is designed to enable the simulation of any important synoptic scale features at courser resolution, while incorporating a high-resolution grid over the primary area(s) of interest. In this manner, the computational requirements associated with use of a high-resolution grid over a large domain are avoided. For this study, the MM5 modeling system will be applied for a much larger area than that used for the UAM-V modeling. The modeling domain was presented in Figure 4-2 and consists of an extended outer grid with approximately 108 km horizontal resolution and four inner (nested) grids with approximately 36, 12, and 4 km resolution, respectively. A Lambert Conformal map projection will be used for the application, to minimize the distortion of the grids within the area of interest. A one-way nesting procedure in which information from the simulation of each outer grid is used to provide boundary conditions for the inner grids will be employed.

To facilitate the realistic simulation of processes within the atmospheric boundary layer, variable surface parameters (including albedo, roughness length, and moisture availability) and a high-resolution planetary boundary layer (PBL) parameterization will be used for the simulations. The PBL parameterization also requires use of a multi-layer soil temperature model (an otherwise optional feature of MM5).

For the coarse grids, the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch, 1990) will be used to parameterize the effects of convection on the simulated environment. This feature will not be employed for the high resolution grids (AB and C) where an explicit moisture scheme (stable precipitation) will be used.

The MM5 model supports four-dimensional data assimilation (FDDA), a procedure by which observed data are incorporated into the simulation. FDDA option include (1) “analysis nudging” in which the simulation variables are relaxed or “nudged” toward an objective analysis that incorporates the observed data and (2) “obs nudging” in which the variables are nudged toward individual observations. These two approaches to FDDA are described in some detail by Stauffer and Seaman (1990) and Stauffer et al. (1991). For this study, analysis nudging will be used for all variables.

The data for preparation of the terrain, initial and boundary condition, and FDDA input files for this application will be obtained from NCAR. The MM5 input files will be prepared using the preprocessor programs that are part of the MM5 modeling system (Gill, 1992).

The MM5 modeling system was recently modified to include the output of the internally calculated vertical exchange coefficients (K_v). The K_v values are intended to represent non-local or multi-scale diffusion coefficients (rather than local diffusion coefficients) as described by (Hong and Pan, 1995). This information will be used to specify the vertical exchange coefficients required by the UAM-V modeling system.

For each simulation period, the model will be initialized at 0000 GMT on the first day of the period. Thus, the MM5 simulation period will include a five-hour initialization period, before the output will be used to prepare inputs for the UAM-V model. For the three outer grids, the MM5 will be run continuously for the nine-day simulation period. For the higher-resolution grid, the model will be reinitialized after each three days of simulation. Each re-initialization will also include an additional 5-hour initialization period. Re-initialization times may vary based on a review of the simulation results. The input fields from each simulation will be inspected to ensure that piecing together the simulations does not create discontinuities in the meteorological inputs (the use of FDDA will alleviate this possibility).

The time step used for the simulations will range from several minutes for the outermost (approximately 108 km) grid to approximately 12 seconds for the innermost (approximately 4 km) grid.

The MM5 output will be postprocessed to correspond to the UAM-V modeling domain and the units and formats required by the modeling system using the MM52UAMV postprocessing software. Wind, temperature, water-vapor concentration, pressure, vertical exchange coefficient, cloud-cover, and rainfall-rate input files containing hourly, gridded estimates of these variables will be derived from the MM5 output. Surface temperature and solar radiation will be postprocessed for use in preparing the mobile-source and biogenic emissions estimates.

Quality Assurance of the Meteorological Inputs

The MM5 simulation results will be evaluated using graphical and statistical analysis. A list of graphical and statistical products is included at the end of this section. The overall evaluation of the MM5 results will include the following elements. For the outer grids, examination of the MM5 output will focus on representation of the regional-scale meteorological features and airflow patterns and will include a comparison with weather maps as well as the items listed below. A more detailed evaluation of the results for the inner (high-resolution) grid will emphasize representation of the observed data, terrain-induced and other local meteorological features, and vertical mixing parameters. To the extent possible, the modeling results will be compared with observed data. In the absence of data, they will be examined for physical reasonableness as well as spatial and temporal consistency. Since data assimilation will be used, a comparison with the observed data primarily serves as a check on the data assimilation but can also reveal potential bias in the meteorological inputs. The ability of the MM5 model to reproduce observed precipitation patterns will be qualitatively assessed by comparing the simulated and observed rainfall patterns (based on NWS data). A detailed analysis of the timing and amount of the precipitation will not be performed.

The UAM-V ready meteorological inputs will also be plotted and examined to ensure that the characteristics and features present in the MM5 output are retained following the postprocessing step.

The following graphical summaries will be prepared to facilitate the review/evaluation of the meteorological inputs:

- 3-dimensional visualizations of the MM5 output using the WXPortal software (an enhanced version of VIS-5D)
- x-y cross-section plots of the MM5 wind fields for several levels and times with observations overplotted for MM5 Grids 1, 2, and 3
- x-y cross-section plots of the UAM-V ready wind, temperature, water-vapor concentration, vertical exchange coefficient, cloud-cover, and rainfall-rate fields for several times and levels (as appropriate).

If the plots or statistics suggest that certain of the features or components of the meteorology are not well represented by MM5, the MM5 application and postprocessing procedures will be reexamined, and additional modeling or processing may be conducted to improve this representation.

Evaluation of the meteorological inputs will continue as the diagnostic analysis and model performance evaluation proceeds. The process analysis feature of UAM-V will also be used to further examine the role of the meteorological inputs in determining the simulated concentration patterns and levels (and their contribution to good or poor model performance). If the UAM-V results suggest that certain of the features or components of the meteorology are not well represented by MM5, the MM5 application and postprocessing procedures will be reexamined, and additional modeling or processing may be conducted to improve this representation.

There are no specific criteria as to what constitutes an acceptable set of meteorological inputs. Similarly, there is no guarantee that the MM5 results will provide the basis for a successful modeling exercise. Problems that can be identified and corrected within the resource and time constraints of this study will be addressed. Others will be documented and recommendations for future applications will be developed.

Air Quality Input Preparation

Air Quality Input Requirements

There are three UAM-V air quality input files that define pollutant concentrations for each of the UAM-V state species (1) throughout the three-dimensional grid at the initial simulation time (coarse-grid only), (2) along the lateral boundaries of the modeling domain for each hour of the simulation period, and (3) along the top of the modeling domain for the entire simulation period.

Air Quality Data

For each simulation period, pollutant concentration data for all monitoring sites located within the modeling domain will be obtained from the EPA Aerometric Information Retrieval System (AIRS) and will be supplemented with data from the CASTNET and SCION data collection programs. Species will include ozone, NO, NO_2, CO, and hydrocarbons, as available. It is expected that there will be fewer measurements of the precursors species, compared to ozone. Estimates of background concentrations of the various pollutants will be obtained from EPA (1991b).

Air Quality Tools and Procedures

Preparation of the initial and boundary condition input files will entail the application of the air quality preprocessor programs included as part of the UAM-V modeling system. The model will be initialized at 0000 EST on the first day of each simulation period. Initial conditions will be obtained through the interpolation of observed data. Note that the degree to which the observations can represent the initial concentration fields will depend upon data availability. To avoid the unrealistic interpolation of the observed data to unmonitored areas, a homology mapping technique in which data from actual sites are assigned to the centroids of unmonitored counties will first be employed. Development and preliminary evaluation of this technique is described by Iwamiya and Douglas (1999). This will provide more complete geographical coverage for the interpolation; the resulting dataset used in the interpolation will consist of both actual and homologue monitors. This will provide more complete geographical coverage for the interpolation; the resulting dataset used in the interpolation will consist of both actual and homologue monitors. Initial conditions aloft will be set equal to EPA default values for each pollutant species.

The primary reason for using a nested-grid, regional-scale modeling configuration is to reduce the uncertainty in the boundary conditions for the area of interest. In this case, lateral boundary conditions need only be specified for the outermost (coarse-grid) domain. Top boundary conditions are specified for all domains in a single file. For this study, the lateral and top boundary concentrations for all pollutants will initially be set equal to continental background values. Recommended concentrations include 40 ppb for ozone, 1 ppb for NO_x (0 ppb for NO; 1 ppb for NO_2), 25 ppb of hydrocarbons (divided among the lumped hydrocarbon species according to the default CB-V speciation profile), and 200 ppb of CO. All other species will be set equal to the EPA default concentrations given by EPA (1991b). The boundary condition value for ozone will be updated for each simulation day using a “self-generating” boundary condition estimation technique. Using this technique, an average ozone concentration from the upper layer of the modeling domain is calculated for the last hour of each day and is used to specify the ozone boundary value (along the lateral and top boundaries) for each subsequent day. In this manner, regional-scale build up of ozone can be represented in the simulation.

The lack of pollutant concentration data (especially aloft) as well as the length of the simulation periods precludes a more detailed specification of the boundary conditions. However, given the geographical extent of the modeling domain beyond the primary area of interest, the coarse-grid boundary conditions are not expected to significantly influence the simulation results within the area of interest. As noted in a subsequent section of the protocol document on diagnostic and sensitivity testing, this assumption will be tested as part of the modeling analysis.

Quality Assurance of the Air Quality Inputs

Tabular summaries of the initial and boundary values for ozone, NO, NO_2, CO, and selected hydrocarbon species will be prepared. Stepwise quality assurance of the air quality input preparation procedures will also be conducted.

Land-Use Input Preparation

Land-Use Input Requirements

A gridded land-use file is required for the full domain and each subdomain.

Land-Use Data

The surface characteristics file will be prepared using the latest available 200-m resolution land-use data obtained from the U.S. Geological Survey (USGS). Each of the categories in the USGS land-use database will be assigned to one of the 11 UAM-V categories. These include urban, agricultural, range, deciduous forest, coniferous forest (including wetlands), mixed forest, water, barren land, non-forest wetlands, mixed agricultural and range, and rocky (low shrubs). These data will be supplemented, to the extent possible, with more refined local data, if available.

Land-Use Tools and Procedures

Preparation of the land-use input files (for the full domain and each subdomain) will entail the application of the land-use preprocessor program included as part of the UAM-V modeling system. The 200-m resolution data are aggregated to the grid cells and the percent distribution among the categories is calculated. The resulting distribution for grid cells along the Gulf Coast will be carefully examined and refined, as needed, to better reflect the high-resolution data along the land-water boundary.

Quality Assurance of the Land-Use Inputs

Plots of the percentage distribution of land-use for each of the 11 land-use categories will be prepared and examined. Stepwise quality assurance of the land-use input preparation procedures will also be conducted.

Chemistry Input Preparation

Chemistry Input Requirements

Application of the UAM-V modeling system requires preparation of several additional input files that contain information on albedo, ozone column, photolysis rates, and chemical reaction rates. This information is required for the full domain and each subdomain.

Ozone Column Data

For each simulation period, day-specific ozone column data will be obtained from the National Aeronautics and Space Administration (NASA).

Chemistry Related Input Tools and Procedures

Preparation of the chemistry related input files will entail the application of the standard preprocessor programs included as part of the UAM-V modeling system. The range of ozone column values for the entire domain for each simulation period will be calculated for use in the photolysis rates preprocessor program. The haze parameter for UAM-V (aerosol optical depth) will be set to 0.094 (a value typical of rural conditions) for the entire modeling domain. Albedo will be specified according to land-use type (based on information contained in the surface file) by the albedo/haze/ozone column processor.

Chemical reaction rates, activation energies, and maximum/minimum species concentrations, as used in the validation of the CB-V chemical mechanism against smog chamber data, will be utilized along with appropriate updates for the enhanced treatment of radical-radical termination reactions and isoprene chemistry.

Photolysis rates will be calculated using JCALC preprocessor program, utilizing the values of albedo, haze, and total ozone column information discussed above.

Quality Assurance of the Chemistry Related Inputs

The ozone column values and photolysis rates will be tabulated and examined. Stepwise quality assurance of the chemistry related input preparation procedures will also be conducted.

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6. Model Performance Evaluation

A typical application of the UAM-V modeling system for ozone air quality assessment purposes consists of several simulations, including an initial simulation and a series of diagnostic and sensitivity simulations (designed to examine the effects of uncertainties in the inputs on the simulation results, identify deficiencies in the inputs, and investigate the sensitivity of the modeling system to changes in the inputs). For each simulation, model performance is primarily assessed through graphical and statistical comparison of the simulated pollutant concentrations with observed data. The results of this comparison are used to guide the modeling analysis (through the determination of additional diagnostic and sensitivity simulations) and to assess whether the model is able to adequately replicate the air quality characteristics of the simulation period. Model performance evaluation tests and procedures are described in this section. Diagnostic and sensitivity analyses that may be performed to understand and improve model performance are discussed in Section 7.

EPA guidance (EPA, 1999) stresses the need to evaluate the model relative to how it will be used in the attainment demonstration; that is in simulating the response to changes in emissions. Various aspects of the model performance evaluation, such as assessment of the ability of the model to simulate weekday-weekend differences in concentration levels and patterns, detailed evaluation of the changes in process-level contributions, and comparison with air quality and emissions trends will be used to evaluate the reliability of the modeled response.

Once acceptable model performance is achieved (based on the results of the graphical, statistical, and sensitivity analysis), the simulation is subsequently referred to as the base-case simulation. The establishment of a base-case simulation is integral to the reliable use of the modeling system to assess the effects of changes in emissions on future air quality.

This section of the protocol document describes the procedures to be used to evaluate model performance.

Model Performance Data

Data from all air quality monitoring sites within the ATMOS modeling domain will be used in the evaluation of model performance. For the most part, these include measurements of ozone, NO, NO_2, NO_x, and CO for routine monitoring sites (including photochemical assessment monitoring sites, PAMS) located throughout the region (and primarily in the urban/nonattainment areas). These data will be obtained from AIRS. We will supplement this database with data from the CASTNET and SCION monitoring program. Several CASTNET and SCION monitors are located throughout the Southeast. Data from these sites will typically include higher resolution NO_x measurements (compared to the routine monitoring sites) and may also include measurements of hydrocarbon species. Data from special studies commensurate with the simulation periods will also be solicited and incorporated as time and resources permit. Note that the analysis and use of special-study data can sometimes be very resource intensive.

Model Performance Objectives

As noted earlier, the overall objective of a model performance evaluation is to establish that the modeling system can be used reliably to predict the effects of changes in emission reductions on future-year ozone air quality and to evaluate the effectiveness of possible attainment demonstration strategies. Specific objectives for the ATMOS study include: (1) ensuring that the regional-scale modeling results provide appropriate boundary conditions for the primary area of interest (Grid 3), (2) ensuring that the ozone concentration patterns and levels and the day-to-day variations in these are well represented, and (3) ensuring that the modeling system exhibits a reasonable response to changes in the inputs (and that the inputs do not contain significant biases or compensating errors).

Model Performance Evaluation Procedures

The evaluation of model performance will follow the general procedures outlined in this section. Variations to these may be proposed and incorporated during the course of the study to address specific issues that arise. All additions/changes will be discussed with the ATMOS Technical Committee.

Model Performance Evaluation Components

The evaluation of model performance will include both qualitative and quantitative components. For each simulation conducted as part of the base-case modeling analysis, a variety of graphical and statistical analysis products will be prepared. These are listed and described in the remainder of this section and will provide the basis for the model performance evaluation. The analysis and integration of these results, relative to the objectives (as given earlier in this section), will complete the evaluation of model performance.

Geographical Considerations

The simulation results for the full domain and each subdomain will be examined using a variety of graphics, metrics, and statistics (these are summarized later in this section). Analysis of results for the coarse-grid (36 and 12-km resolution) domains will emphasize representation of the regional-scale concentration levels and patterns, as well as day-to-day variations in regional-scale air quality. Statistics will be calculated for the coarser grids, but are not expected to be very meaningful for the scale represented by these grids (due to the fact that the data are representative of a much smaller scale). A more detailed analysis of the results will be performed for the high-resolution (4-km) grid and subregions thereof. This will include the analysis of the magnitude and timing of site-specific concentrations (1-hour and 8-hour), a more rigorous statistical evaluation (compared to the coarser grids), and the use of process analysis (for selected simulations for all or portions of Grid 3).

Temporal Considerations

The ability of the modeling system to depict the day-to-day differences in ozone concentration, as indicted by the observations, will be examined for each domain and episode period. Diurnal variations in ozone for the coarser grids will be examined relative to the boundary condition estimates for the finer grids. Site-specific, hourly variations for ozone and precursor species will be examined (using time-series plots and statistical measures) for sites within the high-resolution domains.

The analysis of model performance will focus on 1-hour concentrations of ozone and other species, since the data are typically reported as hourly values. However, the ability of the model to represent maximum 8-hour ozone concentration is related to its ability to represent the hourly values that comprise the 8-hour maximum. Thus, a comparison of maximum 8-hour average ozone concentration will also be performed for the high resolution grids.

As the modeling study progresses, variations in model performance among the simulation periods will also be examined. Specifically, differences in model performance among the simulation periods will be documented and reasons for the differences will be examined.

Species

All relevant species represented by the observed data within the high-resolution domains will be included in the model performance evaluation. We will also consider the calculation of ratios or other derived parameters. The use and interpretation of ratios will be based on discussions with the ATMOS Technical Committee.

Summary of Graphical Displays, Metrics, and Statistical Parameters

Graphical displays and statistical/tabular summaries of the UAM-V simulation results will provide the basis for model performance evaluation and will be used to guide the interpretation and use of the UAM-V simulation results. For each simulation performed as part of the base-case modeling analysis, the graphical displays and tabular summaries will include:

- Isopleth plots of daily maximum simulated ozone concentration (1-hour and 8-hour), with observed values overplotted for all UAM-V grids
- Time-series plots (with range shading) of hourly ozone, NO, NO_2, NO_x, VOC, and CO concentrations for each monitoring site (and possibly other unmonitored locations) within Grid 3
- Scatter plots of hourly ozone (and possibly NO, NO_2, NO_x, VOC, and CO concentrations and selected indicator species) for monitoring sites within Grids 1, 2, and 3
- Scatter plots of 8-hour maximum ozone concentration for each monitoring site within Grids 1, 2, and 3
- Scatter plots comparing the time of the simulated and observed 8-hour maximum ozone concentrations for each monitoring site within Grids 1, 2, and 3
- Standard SAI list of 20 metrics and performance statistics for 1-hour ozone (as listed in Table 6-1, these include various max, min, mean, accuracy, bias, error, residual, and ratio-based parameters) for Grids 1, 2, and 3
- EPA recommended average accuracy statistics for 8-hour ozone
- Time-series plots and bar charts of selected metrics and statistics for ozone for Grids 1, 2, and 3
- Animations of simulated ozone concentrations for selected grids/levels (and selected simulations).

These plots and tabular summaries will be used to display/convey the results of a single simulation or to compare two different simulations, as appropriate. In the latter case, the plots and animations may be presented as concentration differences.

If the UAM-V process-analysis technique is employed for a given simulation, the process-analysis results (for ozone, NO_x, and VOC) will be displayed using SAI's standard 3-panel plots which show the hourly contribution (separately and cumulatively) and the daily net contribution for each simulation process. These will be used to display the results of a single simulation or to compare two different simulations, as appropriate.

Determination of Acceptable Model Performance

An integrated assessment of the above information (obtained as part of the base-case modeling analysis) will be used to document and qualitatively and quantitatively assess whether an acceptable base-case simulation has been achieved. Certain of the statistical measures will be compared to the EPA recommended ranges for acceptable model performance for urban-scale photochemical model applications. EPA has provided ranges for three key statistical measures for 1-hour ozone. The measures and recommended ranges are as follows: unpaired accuracy of the peak concentration (± 20 percent), normalized bias (± 15 percent), and normalized gross error (35 percent). We will also examine the average accuracy of the peak concentration and compare this with the range for the unpaired accuracy. These criteria are most applicable for the assessment of model performance for the high-resolution grid and/or selected urban-scale subregions thereof. However, they will also be used to guide the assessment of model performance for the regional-scale domains (Grids 1 and 2). The additional statistical measures recommended by EPA in the draft guidance for 8-hour ozone modeling will also be calculated and compared with the recommended ranges. These include the domain-wide average accuracy of the 8-hour ozone peak and the site-specific average accuracy of the peak over all simulation days. The recommended range for both of these measures is ± 20 percent. The 8-hour statistics will be calculated for the high-resolution grid and selected subregions only.

Use of Model Performance Results to Guide the Interpretation and Use of Modeling Results in the Attainment Demonstration

Information obtained as part of the model performance evaluation will be carried through the analysis and used to guide the interpretation and use of the results in the attainment demonstration. A simple example of such use is the case where ozone concentrations are overestimated for one or more sites in the base-case simulation. It is possible that the overestimation could affect the response of the modeling system to emissions changes. If the site(s) for which ozone is overestimated show a different result in the attainment demonstration than most other sites, and there are no other apparent reasons for these differences, the overestimation might explain the different response. This would be further examined and possibly offered as “weight of evidence”. As a second example, differences in model performance among days or episodes might cause a different weighting of the results in the attainment demonstration analysis.

Table 6-1. Standard List of UAM-V Simulation Metrics and Performance Statistics.

Number of data pairs
Maximum domain-wide simulated value
Max. station-wide sim. value
Maximum observed value
Domain-wide unpaired accuracy
Station-wide unpaired accuracy
Average accuracy of peak
Normalized bias
Normalized gross error
Fractional bias
Fractional gross error
Ratio of bias to mean observation
Ratio gross error to mean observation
Maximum residual
Minimum residual
Mean unsigned error
Mean residual
Mean simulated value
Mean observation
Root mean square error
Standard deviation of fractional bias

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7. Diagnostic and Sensitivity Analysis

In accordance with EPA guidance, diagnostic and sensitivity analysis will be used in this study to:

- better understand the simulation results
- obtain information that will help to prioritize efforts to improve/refine model inputs
- obtain insights in the effectiveness of various control strategies
- assess the “robustness” of a control strategy.

The first two bullet items pertain to the base-case modeling analysis and are addressed in this section of the protocol document. The latter two items pertain to the future-year analysis and are addressed in Sections 8 and 9, respectively.

The number and nature of the diagnostic and sensitivity simulations performed as part of the base-case modeling effort will likely vary by episode, based on the inputs and/or assumptions used in preparing the inputs and the simulation results (for the initial and diagnostic/sensitivity simulations). They will include simulations incorporating modification or refinement of the inputs as well as a detailed analysis of the simulation processes (using the process analysis feature of UAM-V).

Determination of Appropriate Diagnostic/Sensitivity Simulations

The exact simulations to be performed for each simulation period will be determined based on a review of the initial (and subsequent diagnostic/sensitivity) simulations results or knowledge of sources of uncertainty in the inputs. Up to four diagnostic/sensitivity simulations (not including the future-year emission sensitivity simulations described in Section 8 of the protocol document) will be performed for each simulation period. At least one simulation will investigate the use of “clean” values (as defined in Section 5) for the coarse-grid boundary conditions. Design of the simulations will consider the eventual use of the modeling results in the relative sense (in the attainment demonstration). Specification of the diagnostic and sensitivity simulations will be made in conjunction with the ATMOS Technical Committee.

Diagnostic/Sensitivity Analysis Procedures

All diagnostic and sensitivity simulations will be conducted using the general procedures outlined in Section 5 and 6 of the protocol document. Per EPA guidance, adjustment to the inputs to improve model performance will be within reasonable bounds. Review of the results will consider the possible effects of any modifications on the calculation of relative reduction factors in the attainment demonstration.

Use of the Diagnostic/Sensitivity Analysis Results

The results of the diagnostic and sensitivity analyses may be used to (1) modify or enhance inputs, (2) improve model performance, and (3) guide the interpretation and use of the modeling results in the attainment demonstration. Errors in the inputs that are uncovered as part of the diagnostic/sensitivity analysis will be documented and corrected. Adjustment to the inputs to accommodate uncertainty will be within reasonable bounds and will not be commensurate with poorer model performance (EPA, 1999). For example, as noted in Section 5, the UAM-V results may indicate that additional review of the meteorological inputs, re-application of the MM5, or re-postprocessing of the MM5 output is required. All such modifications/adjustments to the inputs will be technically justifiable, and will be documented. Finally, information obtained as part of the diagnostic/sensitivity analysis will be carried through the analysis and used to guide the interpretation and use of the results in the attainment demonstration. For example, if we find as part of the diagnostic analysis (using process analysis) that high simulated ozone concentrations in a given portion of the domain are due to advection of precursors into the area, we would design the control strategy to include emission reductions in the upwind area. Process analysis could then be used to assess whether the reductions were sufficient/beneficial for 8-hour ozone attainment.

8. Future-Year Modeling

Once an acceptable base case has been achieved, the UAM-V can be used to predict future-year air quality and to evaluate the effectiveness of attainment strategies. In this section, we summarize the procedures to be followed in conducting future-year modeling to support an attainment demonstration for the ATMOS areas of interest.

Selection of a Future Year

The ATMOS EAC attainment demonstration will be performed for the year 2007, and a maintenance simulation will be performed for 2012 to assess the effects of growth. This is consistent with EPA guidance regarding 8-hour attainment demonstrations for traditional nonattainment areas.

Future-Year Emission Inventory Preparation

The future-year modeling for the ATMOS EAC modeling will focus primarily on the year 2007. Prior to preparing the 2007 inventory, a “current” year inventory for 2001 will be prepared for the 1999 episode. This will put both episodes on the same current year and will allow for the calculation of the future-year design value using a consistent base-year design value. To prepare the future baseline inventory for 2007, we will apply growth and control factors to the 2001 base-year emission inventory. To the extent that such data are available, growth and control factors will be obtained from the states of Arkansas, Tennessee, and Mississippi. In the absence of state-specific data, default growth projections prepared by the Bureau of Economic Analysis (BEA) or the Economic Growth Analysis System (EGAS) will be applied based on 2-digit SIC code for point sources and on the EPS 2.5 default projection factor assignments by source category code for area and mobile sources. The control factors to be applied will represent reductions in emissions that should occur as a result of existing control regulations. For mobile sources, VMT estimates provided by EPA for each of the states for 2007 will be used along with the MOBILE model to estimate mobile emissions. Again, state-specific or local data will be used to the extent available.

The future-year baseline emissions inventory will be prepared in accordance with EPA guidance, *Emissions Inventory Guidance for Implementation of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations* (EPA-454/R-99-006, April 1999), and will incorporate emission reductions associated with the NO_x SIP Call and the Tier II low-sulfur fuels and vehicle standards program.

Specification of Other Inputs for Future-Year Simulations

With the exception of the emission inventories (and the boundary conditions which are “self-generating”), all inputs for the future-year simulations will be identical to those for the corresponding base-case simulation.

Future-Year Modeling

The objective of the future-year modeling exercises is to evaluate the likelihood of future-year compliance with the 8-hour ozone NAAQS and, as necessary, assess the effectiveness of various control strategies to improve ozone air quality in the Nashville, Knoxville, Chattanooga, Memphis, and Tri-Cities EAC areas, and Putnam, Haywood, and Lawrence county EAC areas. The future-year modeling analysis will include a future-year baseline simulation, a series of “across-the-board” emission sensitivity simulations, and specific control- or attainment-strategy simulations. The present modeling analysis includes the establishment of a 2007 baseline simulation, a series of approximately XX across-the-board emission sensitivity simulations and approximately XX control-strategy simulations.

Future-Year Baseline Simulation

The future-year baseline simulation incorporates the effects of population and industry growth (or, in some cases, decline) as well as national or statewide control measures or programs that are expected to be in place by the attainment date. The future-year baseline emissions inventory is based on typical summer day emissions, with adjustments for source-specific and episode-specific information. The baseline simulation results provide the starting point for assessment of the effects of further emission reductions on future ozone air quality.

Emissions-Based Sensitivity Simulations

One of the objectives of the future-year modeling exercises is to evaluate the likelihood of future-year compliance with the 8-hour ozone NAAQS and, as necessary, assess the effectiveness of various effective control strategies to improve ozone air quality in the ATMOS area, in general, and in each of the EAC areas, in particular. This will be accomplished by first conducting a series of emission reduction sensitivity simulations. As part of the ATMOS analysis of the 1999 episode, a series of emission reductions simulations have been conducted for a future- baseline year of 2010. Much of what has been learned in these sensitivity simulations for the 1999 episode will be utilized in designing sensitivity simulations for the second ATMOS episode (June 2001).

The sensitivity analysis will involve an initial set of simulations reflecting simple, across-the-board emission reductions from the established 2007 baseline inventory. The modeling effort may include a number of across-the-board emission sensitivity simulations involving varying reductions in VOC and NO_x emissions. An example set of sensitivity simulations is as follows:

- 15 percent reduction in anthropogenic VOC emissions
- 15 percent reduction in anthropogenic NO_x emissions
- 35 percent reduction in anthropogenic VOC emissions
- 35 percent reduction in anthropogenic NO_x emissions
- 15 percent reduction in anthropogenic VOC emissions and 35 percent reduction in anthropogenic NO_x emissions
- 35 percent reduction in anthropogenic VOC emissions and 15 percent reduction in anthropogenic NO_x emissions
- 35 percent reduction in anthropogenic VOC and NO_x emissions.

The final set and number of simulations to be performed will be determined in consultation with the ATMOS Operations Committee. The results of the emission sensitivity simulations will be compared with the 2007 baseline simulation results using difference plots and through comparison of the metrics to determine the relative effectiveness of the different types and amounts of emission reductions, as well as any synergistic effects (i.e., the decrease in maximum 8-hour ozone concentration obtained from the combined VOC and NO_x reductions may be greater than the sum of the decreases when the emission reductions are applied separately). Approximately 12 emission sensitivity simulations (of varying complexity) will be conducted.

Control-Strategy Simulations

On the basis of the results of the emission reduction sensitivity modeling, control strategy options will be identified, simulated, and evaluated in this task. Draft guidance for demonstrating attainment of the 8-hour NAAQS has been developed by EPA. This guidance will provide the methodologies to be followed in conducting a modeling attainment demonstration, as described in more detail in Section 9 of the protocol document.

The control scenarios to be simulated will likely involve a combination of reductions from all source sectors including mobile, area, and point sources. The various options can be evaluated in terms of the cost effectiveness of reducing future-year ozone concentrations. The simulation results will be presented with the graphical and statistical tools used for the sensitivity modeling analysis. Special products will be prepared, if necessary, to meet the reporting requirements for the attainment demonstration exercise as outlined in the EPA guidance document. Up to six control strategy simulations (of varying complexity) will be performed.

Display and Presentation of Future-Year Simulation Results

Graphical displays and statistical/tabular summaries of the UAM-V simulation results will be used to assess the future-year simulation results (and to compare the base- and future-year ozone concentrations). The graphical displays and tabular summaries will include:

- Isopleth and isopleth difference (2007 minus 1999) plots of daily maximum simulated 1-hour and 8-hour ozone concentration
- Animations of simulated ozone concentrations and concentration differences for selected simulations
- Interactive ACCESS™ database (referred to as ACCESS™ Database for Visualizing and Investigating Strategies for Ozone Reduction or ADVISOR) containing information for review, comparison, and assessment of the simulation results by all study participants. The database will contain both emissions and simulated ozone concentrations (as represented by several different metrics) for all grids and selected subregions of the domain. Users will be able to view (and extract) the data in spreadsheet format and to create plots, the contents of which will reflect various user-specified options.

  Metrics will include:

  – maximum 1-hour ozone concentration (ppb)

  – maximum 8-hour ozone concentration (ppb)

  – number of grid cell · hours with maximum 8-hour ozone concentrations ≥ 85 ppb

– number of grids cells with daily maximum 8-hour ozone concentrations ≥ 85 ppb
– total ozone exposure (ppb · grid cell · hour)
– exceedance ozone exposure (ppb · grid cell · hour) for concentrations ≥ 85 ppb
– population exposure (to concentrations ≥ 85 ppb)
– total emissions (NO_x, VOC)

Options for displaying the metrics will include:

– value
– difference (relative to a selected base simulation)
– effectiveness (change in ozone metric relative to the change in emissions, again relative to a selected base simulation)

Geographies will include:

– Grid 1: Outer 36 km X 36 km grid
– Grid 2: Intermediate 12 km X 12 km grid
– Grid 3: Inner 4 km x 4 km inner grid
– Sumner, Davidson, Wilson, & Rutherford Counties, TN (Nashville)
– Knox, Anderson, Jefferson, Sevier, and Blount Counties, TN (Knoxville)
– Shelby, DeSoto, and Crittenden Counties (Memphis)
– Shelby County, TN
– DeSoto County, MS
– Crittenden County, AR
– Lee County, MS (Tupelo)
– Pulaski County, AR (Little Rock)
– Hamilton County, TN; Walker and Catoosa Counties, GA (Chattanooga)
– Nashville EAC Area: (Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson counties)
– Knoxville EAC Area: (Anderson, Blount, Know, Loudon, Sevier, Union, and Jefferson counties)
– Chattanooga EAC Area: (Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa counties, (Georgia))
– Memphis EAC Area: Shelby, Tipton, and Fayette counties (Tennessee); Crittenden County, (Arkansas); De Soto County, (Mississippi)
– Tri-Cities EAC Area: (Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington counties)
– Haywood County
– Lawrence County
– Putnam County

In addition to these specific areas, the ozone monitoring sites in the ATMOS Grid 3 will also be included in the ADVISOR database.

The future-year modeling results will also be reviewed using the procedures outlined in the EPA guidance document on the use of models and other analyses in attainment demonstrations for the 8-hour ozone NAAQS.

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9. Attainment Demonstration

The procedures to be followed in conducting the attainment demonstration analysis are outlined in this section of the protocol document. The attainment demonstration analysis for the ATMOS EAC study will include application of the new modeled attainment test (EPA, 1999) as well as other corroborative analyses. As this 8-hour modeling guidance is still in draft form, we will adapt the final attainment demonstration procedures to reflect any changes to the draft guidance that might be issued by EPA in time for use in this study. Given that the results of the modeling analysis are unknown at this time, the details of the corroborative analyses cannot be specified. However, the general approach to identifying and conducting such analyses is presented. The present modeling analysis includes the preparation of the ADVISOR database to support the application of the attainment demonstration procedures.

Geographical Considerations

The ATMOS ADVISOR database and associated analysis procedures outlined in this and the previous section are designed to support a separate 8-hour attainment demonstration analysis for each of the areas of interest (as required by the pending nonattainment designations). The current list of areas includes the Nashville, Knoxville, Chattanooga, Memphis, and Tri-Cities EAC areas, and Putnam, Haywood, and Lawrence county EAC areas. For each area of interest, the analysis will include the modeled attainment test, any requisite screening tests, and additional corroborative analysis.

Modeled Attainment Test

The modeled attainment test as described in the draft EPA guidance on 8-hour ozone attainment demonstrations (EPA, 1999) will be included along with all base- and future-year simulation results in the ATMOS ADVISOR database. Key implementation issues are presented and discussed in this section.

An important component of the attainment test is the calculation of a relative reduction factors (RRF) for each site and each simulation day, for each relevant (attainment demonstration) simulation. The RRF represents the ratio of the future-year daily maximum 8-hour ozone concentration to the corresponding base-year value. It is calculated for each site using simulated ozone concentrations within the “vicinity” of the site. For the 4-km ATMOS subdomain, “vicinity” will be defined as within one grid cell of the grid cell in which the monitoring site is located. That is, the nine grid cells surrounding a monitoring site will be included. For the 4-km grid this results in a radius of influence of approximately 4 km.

This radius of influence is smaller than that suggested in the EPA guidance document; however, there are good technical reasons to refine the default definitions given the EPA guidance document. Use of a 15-km radius of influence, as recommended by EPA, would mean that the influence zone for a number of sites would encompass (or nearly encompass) other nearby sites. This would occur in all three primary areas of interest, and for sites that exhibit very different concentration characteristics during the episode period. For example, several of the Knoxville area monitoring sites are located with 15 km of one another but at very different elevations. As a result they frequently experience very different ozone peaks. The use of a more limited (4 km) radius of influence, in this case, would accommodate the geographic and meteorological variability and the observed concentration gradients.

Use of a smaller value than the EPA default will ensure that the sites are considered independently from one another, and will preserve the site-specific nature of the attainment-demonstration exercise. This is important in the context of an attainment demonstration that is based on site-specific design values. In using the simulation results to adjust site-specific design values, it is important that the simulation results reflect the concentration characteristics of specific sites (not other nearby sites, as would be the case with the larger radius of influence).

The RRF for a given monitor will be calculated using the grid-cell level simulated maximum 8-hour ozone concentration in the vicinity of the monitor, as defined above. The grid cell containing this value may be different for the base year and the future year, since changes in emissions can alter the timing of the chemistry and the location of the maximum value. This approach is also consistent with the use of a high-resolution grid, since relocation of the maximum to a different grid cell in the vicinity of a monitoring site will not represent a large spatial shift.

The RRF can be calculated for a single day or as an average over multiple days. The ADVISOR database is designed to allow the user to specify which simulation days will be included in the calculation of the RRF. The user may select the day(s) directly or use one of three “automated” day selection options. These include (1) for each simulation day for which the simulated maximum 8-hour ozone value is greater than a user-specified value (including the EPA recommended default of 70 ppb), (2) for all observed 8-hour ozone exceedance days, and (3) for all days for which the base-case simulation results are within a user-specified range of model performance.

The estimated design value (EDV) for each site is then calculated by multiplying the RRF by the site-specific design value. In the ADVISOR database, the user will be able to select any of the design values from the period 1997 through 2002, or the maximum of these. The predicted future design value for each area will then be the maximum of the values for the monitoring sites within the area. If this value is less than 85 ppb, the test is passed.

Use of the 2000-2002 design value is consistent with date of the new June 2001 episode and the use of the 1999 episode with a “current year” 2001 inventory.

Screening Test

For unmonitored areas within the modeling domain that consistently exhibit simulated exceedances of the 8-hour NAAQS, the EPA recommended screening test will be applied. To apply the screening test to the regional-scale ATMOS domain, we will first define subregions within the domain (encompassing each EAC areas). Within these subregions, we will then adopt the EPA definition of “consistently”[10] to identify locations for application of the screening test. The screening test will be applied using the mean design value for the subregion in which the unmonitored-area exceedance is consistently simulated. The predicted future design value for each area will then be the maximum of the values for all monitored and unmonitored “sites” within the subregion or area. If this value is less than 85 ppb, the test is passed.

[10] Daily maximum 8-hour daily ozone at the location in question is more than five percent higher than near any monitored location on 50 percent or more of the modeled days.

Other Components of the Weight of Evidence Determination

If the modeled attainment and screening tests are passed or nearly passed, states may opt to include additional analyses as part of a “weight of evidence” determination. Current EPA guidance does not encourage a weight of evidence determination if the predicted design value for a given area is greater than or equal to 90 ppb. The specific analyses to be performed for each area will be determined based on the findings and results of the modeling analysis as well as a review of available data and information. EPA (1999) suggests some core analyses. However, the currently available air quality data do not support the reliable use of observation-based models.

Per EPA guidance, the weight of evidence analysis will include additional analysis of the model output for each nonattainment area including (1) relative change in grid-cell-hours with maximum 1-hour ozone concentrations greater than or equal to 85 ppb, (2) relative change in the number of grid cells with 8-hour ozone concentrations greater than or equal to 85 ppb, and (3) relative change in the amount by which the 8-hour NAAQS is exceeded by 1-hour simulated concentrations. Note that each of these will be included in the ADVISOR databases described in Section 8. A large reduction in these metrics would support a weight of evidence argument. In all cases, EPA guidance suggests that a value of 80 percent should be considered to be a large reduction.

A primary objective of the weight of evidence analyses is to use other methods to corroborate the modeling results or to independently assess the potential for attainment. Considerations in designing these analyses include:

- potential or expected effects of model performance problems or other modeling related uncertainties (e.g., emission projection factors) on the outcome of the modeled attainment and screening tests
- representativeness of days as characterized by the episode selection analysis (e.g., are all key regimes represented? are days for which attainment is not simulated included among the key regimes/design-value days?)
- other uses of the observational data (e.g., trends analysis).

Use of Modeling and Corroborative Evidence to Demonstrate Attainment

The attainment demonstration for each area will require an integrated analysis of the modeling results and any corroborative evidence. The relative “weight” of each will be based on an assessment of the confidence (or degree of uncertainty) in the analysis procedures and results (e.g., data completeness, reliability of the methodology, relevant assumptions, credibility of the results), to the extent this can be established.

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10. Documentation

A final report describing the modeling/analysis methods and results will be prepared. A single report will be prepared; however, the results for the individual areas of interest will be presented separately. Preparation of this document is described in this section.

EPA Recommended Elements

Each of the recommended subject areas will be addressed in the final report. These include:

- modeling/analysis protocol
- emissions preparations and results
- air quality/meteorology preparations and results
- performance evaluation for air quality simulation model (and other analyses)
- diagnostic tests
- description of the strategy demonstrating attainment
- data access
- weight of evidence determination
- review procedures used.

The purpose of and issues associated with each subject area is summarized in the EPA guidance document (EPA, 1999).

Outline for Final Report

A draft outline for the final report follows:

Executive Summary (including a discussion of the conceptual description of the 8-hour ozone nonattainment problem for each area of interest)

I. Introduction

A. Background and objectives
B. Modeling grid specification
C. Episode selection/simulation periods
D. Characterization of meteorology and air quality of the modeling episodes

II. Modeling Protocol

III. Base-Case Modeling Emission Inventory Preparation

A. Emissions data
B. Overview of emissions processing procedures
C. Preparation of the area and non-road emission inventory component
D. Preparation of the mobile-source emission inventory component
E. Preparation of point-source emission inventory component

F. Estimation of biogenic emissions

G. Quality Assurance

H. Summary of the Modeling Emission Inventories

IV. Meteorological Modeling and Input Preparation

A. Overview of the MM5 meteorological modeling system and application procedures

B. Presentation of results/model performance evaluation

C. Preparation of UAM-V ready meteorological fields

D. Quality assurance

V. Air Quality, Land-Use, and Chemistry Input Preparation

A. Air quality related inputs

B. Land-use inputs

C. Albedo/haze/ozone column

D. Chemistry parameters

E. Quality assurance

VI. Model Performance Evaluation

A. Initial simulation results

B. Diagnostic and sensitivity analysis

C. Summary of base-case model performance

VII. Future-Year Modeling Exercises

A. Future-year emission inventory preparation

B. Future-year boundary conditions preparation

C. Future-year baseline simulation results

D. Emission sensitivity simulation results

E. Control-strategy simulation results

VIII. Attainment Demonstration *(this will include a subsection for each area of interest and will be completed based on the attainment demonstration runs following final EPA guidance)*

A. Description of the attainment strategy

B. Modeled attainment and screening test results

C. Additional analysis

D. Methods

E. Results

F. Repeat for each type of additional analysis

G. Integrated weight of evidence analysis

IX. Summary of review procedures used

X. Data access procedures

References

11. Summary of Deliverables and Schedule

The following is a list of major deliverables and a schedule for their completion:

Draft modeling protocol document	23 May 2003
Final modeling protocol document	2 weeks after receipt of final comments from EPA (20 June 2003?)
Updated modeling protocol document	As needed
Draft final report	1 December 2003
Final report	4 weeks following receipt of comments from ATMOS technical committee
Modeling tools and databases	31 December 2003

A schedule for the modeling analysis was provided in Figure 1-2.

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12. Archival/Data Acquisition Procedures

The data, input, and output files for the modeling analysis will be available in electronic format. Interested parties should contact the ATMOS Operations Committee chairpersons for information on how to obtain these files. The modeling tools to be used for this study (with the exception of the BEIS and MOBILE models and the CART statistical analysis software, which can be obtained from EPA or other sources) will be included in the deliverables from SAI.

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Appendix B:
Tables for Future-Year Emissions Inventory Preparation

Table B-1
BEA Gross State Product (GSP) Growth factors by 4-Digit ASC for 1999 to 2007 for States of AL, AR, DC, FL, GA and IA

Description	ASC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1679	1.1586	1.1014	1.2174	1.2013	1.1116	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0209	1.0274	0.9972	1.0808	1.0662	1.0143	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Aircraft	2275	1.3337	1.2875	1.2173	1.2628	1.2298	1.2728	Transportation by air
Mobile Sources Marine Vessels	2280	1.0134	1.0884	1.0253	1.1198	1.0346	1.1184	Water transportation
Mobile Sources Pleasure Craft	2282	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Mobile Sources Railroads	2285	1.2486	1.2560	1.3588	1.3145	1.2397	1.2412	Railroad transport.
Mobile Sources Paved Roads	2294	1.1402	1.1470	1.0190	1.2010	1.1771	1.0724	Local & interurban
Mobile Sources Unpaved Roads	2296	1.1402	1.1470	1.0190	1.2010	1.1771	1.0724	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Industrial Processes Food and Kindred Products	2302	1.1012	1.1555	1.0461	1.1391	1.1736	1.0799	Food & kindred
Industrial Processes Primary Metal Production	2303	1.0281	1.1179	1.0000	1.0501	1.0096	1.0511	Primary metals
Industrial Processes Secondary Metal Production	2304	1.0281	1.1179	1.0000	1.0501	1.0096	1.0511	Primary metals
Industrial Processes Mineral Processes	2305	1.0499	1.0924	1.0946	1.0915	1.0902	1.0809	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.1341	1.0953	1.0710	1.1260	1.0486	0.8908	Petroleum products
Industrial Processes Wood Products	2307	1.0844	1.0551	0.8889	1.0377	1.0512	1.1294	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2464	1.2790	1.4000	1.2663	1.2371	1.2426	Rubber & plastics

Description	ASC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Industrial Processes Fabricated Metals	2309	1.0553	1.0918	0.8909	0.9934	1.0835	1.0605	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.8976	0.9770	1.1973	1.2170	1.0877	1.2444	Oil & gas
Industrial Processes Construction	2311	1.0641	1.0700	0.9885	1.1330	1.0998	1.0590	Construction
Industrial Processes Machinery	2312	1.3388	1.3579	1.2310	1.2431	1.3379	1.1995	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.1509	1.0973	1.1200	1.0568	1.1312	1.1195	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Solvent Utilization Surface Coating	2401	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Solvent Utilization Degreasing	2415	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0876	1.0697	1.0041	1.1306	1.1109	1.0474	Personal services
Solvent Utilization Graphic Arts	2425	1.0638	1.0285	1.0137	1.1267	1.1070	1.0263	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2464	1.2790	1.4000	1.2663	1.2371	1.2426	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1552	1.1660	1.0937	1.2140	1.1532	1.1411	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Solvent Utilization All Solvent User Categories	2495	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.1341	1.0953	1.0710	1.1260	1.0486	0.8908	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	0.9872	1.0542	1.0959	1.2511	1.1358	0.9638	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	0.9872	1.0542	1.0959	1.2511	1.1358	0.9638	Pipelines
Storage and Transport Bulk Materials Storage	2530	1.1338	1.0090	1.2392	1.1130	1.1281	1.1213	Mining
Storage and Transport Bulk Materials Transport	2535	1.1338	1.0090	1.2392	1.1130	1.1281	1.1213	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Waste Disposal, Treatment, and Recovery - Landfills	2620	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0503	1.0561	0.9891	1.1334	1.0930	1.0326	Total Population

Description	ASC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Waste Disposal, Treatment, and Recovery - TSDFs	2640	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Miscellaneous Area Sources Agriculture Production - Crops	2801	1.1606	1.1290	1.0000	1.1869	1.1230	1.2078	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1606	1.1290	1.0000	1.1869	1.1230	1.2078	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1671	1.1690	1.0350	1.1700	1.1646	1.1360	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1339	1.1158	1.0396	1.1694	1.1749	1.1045	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.2586	1.2240	1.1429	1.2917	1.2753	1.2052	Business services
Miscellaneous Area Sources Health Services	2850	1.1922	1.1833	1.1405	1.2588	1.2768	1.1432	Health services

Source: Developed from BEA, 1995.

Table B-2
BEA Gross State Product (GSP) Growth Factors by 4-Digit ASC for 1999 to 2007 for States of IL, IN, KS, KY, MD and MI

Description	ASC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1223	1.1304	1.1614	1.1173	1.1583	1.1179	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0503	1.0409	1.0574	1.0293	1.0562	1.0325	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Aircraft	2275	1.2683	1.3536	1.3029	1.3120	1.3482	1.2258	Transportation by air
Mobile Sources Marine Vessels	2280	1.0538	1.1012	1.0905	1.0153	0.9617	1.0681	Water transportation
Mobile Sources Pleasure Craft	2282	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Mobile Sources Railroads	2285	1.2087	1.2585	1.2513	1.1765	1.0927	1.1821	Railroad transport.
Mobile Sources Paved Roads	2294	1.1307	1.1251	1.1228	1.1175	1.1187	1.0822	Local & interurban
Mobile Sources Unpaved Roads	2296	1.1307	1.1251	1.1228	1.1175	1.1187	1.0822	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Industrial Processes Food and Kindred Products	2302	1.0599	1.0679	1.1307	1.0571	1.0084	1.0613	Food & kindred
Industrial Processes Primary Metal Production	2303	0.9951	1.0348	1.0696	1.0555	0.9017	1.0000	Primary metals
Industrial Processes Secondary Metal Production	2304	0.9951	1.0348	1.0696	1.0555	0.9017	1.0000	Primary metals
Industrial Processes Mineral Processes	2305	1.0273	1.0512	1.0284	1.1232	0.9985	1.0684	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.0719	1.1224	1.0982	1.1282	1.1523	1.0652	Petroleum products
Industrial Processes Wood Products	2307	1.0338	1.1148	1.0720	1.1221	1.0629	1.0748	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2330	1.2656	1.2691	1.2341	1.1520	1.2866	Rubber & plastics
Industrial Processes Fabricated Metals	2309	1.0068	1.0527	1.0311	1.1467	1.0111	1.0418	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.8898	0.9427	0.9703	0.9545	1.0000	0.9467	Oil & gas
Industrial Processes Construction	2311	1.0644	1.0653	1.0585	1.0635	1.0507	1.0531	Construction

Description	ASC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Industrial Processes Machinery	2312	1.2091	1.2546	1.2382	1.2140	1.2043	1.2220	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.0620	1.0860	1.0982	1.1293	1.0725	1.1041	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Solvent Utilization Surface Coating	2401	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Solvent Utilization Degreasing	2415	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0669	1.0690	1.0792	1.0613	1.0699	1.0532	Personal services
Solvent Utilization Graphic Arts	2425	1.0365	1.0454	1.0769	1.0303	1.0690	1.0290	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2330	1.2656	1.2691	1.2341	1.1520	1.2866	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1066	1.1436	1.1123	1.1487	1.0661	1.1159	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Solvent Utilization All Solvent User Categories	2495	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.0719	1.1224	1.0982	1.1282	1.1523	1.0652	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	1.0193	1.0203	1.1442	1.0472	1.0641	1.0820	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	1.0193	1.0203	1.1442	1.0472	1.0641	1.0820	Pipelines
Storage and Transport Bulk Materials Storage	2530	1.1815	1.1687	0.9794	1.2185	1.2237	1.0771	Mining
Storage and Transport Bulk Materials Transport	2535	1.1815	1.1687	0.9794	1.2185	1.2237	1.0771	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Waste Disposal, Treatment, and Recovery - Landfills	2620	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0552	1.0479	1.0552	1.0500	1.0776	1.0328	Total Population
Waste Disposal, Treatment, and Recovery - TSDFs	2640	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing

Description	ASC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Miscellaneous Area Sources Agriculture Production - Crops	2801	1.1186	1.1904	1.1337	1.2015	1.1518	1.1599	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1186	1.1904	1.1337	1.2015	1.1518	1.1599	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1172	1.1380	1.1534	1.1338	1.0756	1.0884	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1253	1.1182	1.1437	1.1338	1.1425	1.1028	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.1915	1.2290	1.2382	1.2596	1.2166	1.2031	Business services
Miscellaneous Area Sources Health Services	2850	1.1738	1.1811	1.1762	1.1874	1.2034	1.1492	Health services

Source: Developed from BEA, 1995.

Table B-3
BEA Gross State Product (GSP) Growth Factors by 4-Digit ASC for 1999 to 2007 for States of MO, MS, NC, NE, NY and OH

Description	ASC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1258	1.1566	1.1674	1.1497	1.1116	1.1141	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0395	1.0280	1.0750	1.0446	1.0353	1.0105	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Aircraft	2275	1.1542	1.3505	1.2937	1.2788	1.1465	1.2588	Transportation by air
Mobile Sources Marine Vessels	2280	0.8802	1.0072	1.0668	1.0492	0.8598	1.0281	Water transportation
Mobile Sources Pleasure Craft	2282	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Mobile Sources Railroads	2285	1.2531	1.2256	1.1963	1.2771	1.2004	1.1598	Railroad transport.
Mobile Sources Paved Roads	2294	1.1214	1.0994	1.0441	1.1282	1.0796	1.1258	Local & interurban
Mobile Sources Unpaved Roads	2296	1.1214	1.0994	1.0441	1.1282	1.0796	1.1258	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Industrial Processes Food and Kindred Products	2302	1.1039	1.1235	1.1249	1.0876	1.0091	1.0903	Food & kindred
Industrial Processes Primary Metal Production	2303	1.0165	1.0810	1.1158	1.0645	0.8853	1.0142	Primary metals
Industrial Processes Secondary Metal Production	2304	1.0165	1.0810	1.1158	1.0645	0.8853	1.0142	Primary metals
Industrial Processes Mineral Processes	2305	1.0569	1.0597	1.1164	1.0740	1.0454	1.0375	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.1247	1.1112	1.1804	1.1833	1.0508	1.1216	Petroleum products
Industrial Processes Wood Products	2307	1.0776	1.0716	1.1054	1.0581	1.0364	1.1239	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2550	1.3197	1.2759	1.2416	1.2018	1.1797	Rubber & plastics
Industrial Processes Fabricated Metals	2309	1.0739	1.0548	1.1251	1.0456	0.9689	1.0291	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.9812	1.0061	1.1133	0.9119	0.9995	0.9485	Oil & gas
Industrial Processes Construction	2311	1.0536	1.0784	1.1117	1.0902	1.0205	1.0663	Construction

Description	ASC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Industrial Processes Machinery	2312	1.2346	1.3359	1.2821	1.2307	1.0931	1.2235	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.0734	1.1073	1.1042	1.1175	1.0868	1.0931	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Solvent Utilization Surface Coating	2401	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Solvent Utilization Degreasing	2415	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0717	1.0736	1.0916	1.0673	1.0224	1.0585	Personal services
Solvent Utilization Graphic Arts	2425	1.0487	1.0805	1.1131	1.0408	0.9719	1.0174	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2550	1.3197	1.2759	1.2416	1.2018	1.1797	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1269	1.1150	1.2243	1.1042	1.0639	1.1450	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Solvent Utilization All Solvent User Categories	2495	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.1247	1.1112	1.1804	1.1833	1.0508	1.1216	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	0.9943	1.0620	1.0842	1.0337	1.0638	1.0413	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	0.9943	1.0620	1.0842	1.0337	1.0638	1.0413	Pipelines
Storage and Transport Bulk Materials Storage	2530	1.1278	0.9983	1.0841	1.0661	1.0733	1.0906	Mining
Storage and Transport Bulk Materials Transport	2535	1.1278	0.9983	1.0841	1.0661	1.0733	1.0906	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Waste Disposal, Treatment, and Recovery - Landfills	2620	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0588	1.0419	1.0869	1.0501	1.0182	1.0349	Total Population
Waste Disposal, Treatment, and Recovery - TSDFs	2640	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing

Description	ASC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Miscellaneous Area Sources Agriculture Production - Crops	2801	1.1838	1.1442	1.1009	1.1333	1.1740	1.1656	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1838	1.1442	1.1009	1.1333	1.1740	1.1656	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1178	1.1713	1.1466	1.1406	1.0327	1.1161	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1233	1.1214	1.1704	1.1245	1.0582	1.1192	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.2129	1.2399	1.2951	1.2218	1.1224	1.1994	Business services
Miscellaneous Area Sources Health Services	2850	1.1763	1.1992	1.2619	1.1721	1.1614	1.1590	Health services

Source: Developed from BEA, 1995.

Table B-4
BEA Gross State Product (GSP) Growth Factors by 4-Digit ASC for 1999 to 2007 for States of OK, PA, SC, TN, VA and WV

Description	ASC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1421	1.1179	1.1636	1.2014	1.1715	1.1338	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0432	1.0193	1.0603	1.0551	1.0519	1.0229	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Aircraft	2275	1.2662	1.2724	1.3697	1.3352	1.2586	1.2461	Transportation by air
Mobile Sources Marine Vessels	2280	1.1059	0.9851	1.0546	1.0878	1.0326	1.0177	Water transportation
Mobile Sources Pleasure Craft	2282	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Mobile Sources Railroads	2285	1.2016	1.2162	1.2214	1.2237	1.2718	1.2173	Railroad transport.
Mobile Sources Paved Roads	2294	1.0939	1.1260	1.1236	1.1311	1.1093	1.0957	Local & interurban
Mobile Sources Unpaved Roads	2296	1.0939	1.1260	1.1236	1.1311	1.1093	1.0957	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Industrial Processes Food and Kindred Products	2302	1.0977	1.0645	1.1234	1.1118	1.1256	1.0518	Food & kindred
Industrial Processes Primary Metal Production	2303	1.0935	0.8953	1.1596	1.0676	1.0486	1.0062	Primary metals
Industrial Processes Secondary Metal Production	2304	1.0935	0.8953	1.1596	1.0676	1.0486	1.0062	Primary metals
Industrial Processes Mineral Processes	2305	1.0674	1.0178	1.0620	1.0911	1.0452	1.0237	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.1152	1.0415	1.2691	1.1205	1.1811	1.0816	Petroleum products
Industrial Processes Wood Products	2307	1.0845	1.0979	1.0506	1.1064	1.0914	1.1425	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2588	1.2144	1.2557	1.2579	1.2693	1.3066	Rubber & plastics
Industrial Processes Fabricated Metals	2309	1.1199	1.0018	1.1633	1.0876	1.0470	1.0878	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.9568	1.0256	1.0050	1.0034	1.0902	0.9336	Oil & gas
Industrial Processes Construction	2311	1.0876	1.0364	1.1247	1.0918	1.0907	1.0369	Construction

Description	ASC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Industrial Processes Machinery	2312	1.2321	1.1928	1.3869	1.2828	1.3207	1.1821	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.1151	1.1185	1.1339	1.1007	1.1064	1.0776	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Solvent Utilization Surface Coating	2401	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Solvent Utilization Degreasing	2415	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0786	1.0431	1.1087	1.0826	1.0842	1.0393	Personal services
Solvent Utilization Graphic Arts	2425	1.0001	1.0376	1.1019	1.0689	1.0952	1.0263	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2588	1.2144	1.2557	1.2579	1.2693	1.3066	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1913	1.0798	1.1400	1.1732	1.1310	1.1600	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Solvent Utilization All Solvent User Categories	2495	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.1152	1.0415	1.2691	1.1205	1.1811	1.0816	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	1.0374	1.0231	1.0126	1.0281	1.0341	0.9996	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	1.0374	1.0231	1.0126	1.0281	1.0341	0.9996	Pipelines
Storage and Transport Bulk Materials Storage	2530	0.9565	1.1209	1.1550	1.1194	1.1963	1.1359	Mining
Storage and Transport Bulk Materials Transport	2535	0.9565	1.1209	1.1550	1.1194	1.1963	1.1359	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Waste Disposal, Treatment, and Recovery - Landfills	2620	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0542	1.0379	1.0831	1.0758	1.0786	1.0270	Total Population
Waste Disposal, Treatment, and Recovery - TSDFs	2640	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing

Description	ASC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Miscellaneous Area Sources Agriculture Production - Crops	2801	1.1973	1.1697	1.1338	1.1853	1.1052	1.2984	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1973	1.1697	1.1338	1.1853	1.1052	1.2984	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1610	1.0735	1.2067	1.1574	1.1208	1.0722	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1351	1.0974	1.1629	1.1513	1.1412	1.1134	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.2037	1.1789	1.2934	1.2658	1.2435	1.2511	Business services
Miscellaneous Area Sources Health Services	2850	1.1790	1.1822	1.2648	1.2051	1.2093	1.1628	Health services

Source: Developed from BEA, 1995.

Table B-5
BEA Gross State Product (GSP) Growth Factors by 4-Digit ASC for 2000 to 2007 for State of AR

Description	ASC	AR	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1344	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1484	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1484	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0199	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0489	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0489	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0489	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0489	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0489	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0489	Total Population
Mobile Sources Aircraft	2275	1.2240	Transportation by air
Mobile Sources Marine Vessels	2280	1.0526	Water transportation
Mobile Sources Pleasure Craft	2282	1.0489	Total Population
Mobile Sources Railroads	2285	1.2123	Railroad transport.
Mobile Sources Paved Roads	2294	1.1160	Local & interurban
Mobile Sources Unpaved Roads	2296	1.1160	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.0809	Chemicals
Industrial Processes Food and Kindred Products	2302	1.1373	Food & kindred
Industrial Processes Primary Metal Production	2303	1.1109	Primary metals
Industrial Processes Secondary Metal Production	2304	1.1109	Primary metals
Industrial Processes Mineral Processes	2305	1.0909	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.0895	Petroleum products
Industrial Processes Wood Products	2307	1.0581	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2387	Rubber & plastics
Industrial Processes Fabricated Metals	2309	1.0890	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.9761	Oil & gas
Industrial Processes Construction	2311	1.0632	Construction

Description	ASC	AR	BEA Surrogate
Industrial Processes Machinery	2312	1.2926	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.0779	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1484	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1484	Manufacturing
Solvent Utilization Surface Coating	2401	1.1484	Manufacturing
Solvent Utilization Degreasing	2415	1.1484	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0589	Personal services
Solvent Utilization Graphic Arts	2425	1.0347	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2387	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1460	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.0809	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1484	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0489	Total Population
Solvent Utilization All Solvent User Categories	2495	1.0809	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.0895	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	1.0384	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.0809	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.0809	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.0809	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	1.0384	Pipelines
Storage and Transport Bulk Materials Storage	2530	1.0123	Mining
Storage and Transport Bulk Materials Transport	2535	1.0123	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0489	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0489	Total Population
Waste Disposal, Treatment, and Recovery – Landfills	2620	1.0489	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0489	Total Population
Waste Disposal, Treatment, and Recovery – TSDFs	2640	1.1484	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1484	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1484	Manufacturing

Description	ASC	AR	BEA Surrogate
Miscellaneous Area Sources Agriculture Production – Crops	2801	1.1113	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1113	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1484	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1484	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.0962	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.1869	Business services
Miscellaneous Area Sources Health Services	2850	1.1613	Health services

Source: Developed from BEA, 1995.

Table B-6
BEA Gross State Product (GSP) Growth Factors by 4-Digit ASC for 2001 to 2007 for State of TN

Description	ASC	TN	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.1389	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.1119	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.1119	Manufacturing
Stationary Source Fuel Combustion Residential	2104	1.0368	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0542	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0542	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0542	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0542	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0542	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0542	Total Population
Mobile Sources Aircraft	2275	1.2300	Transportation by air
Mobile Sources Marine Vessels	2280	1.0609	Water transportation
Mobile Sources Pleasure Craft	2282	1.0542	Total Population
Mobile Sources Railroads	2285	1.1587	Railroad transport.
Mobile Sources Paved Roads	2294	1.0880	Local & interurban
Mobile Sources Unpaved Roads	2296	1.0880	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.0805	Chemicals
Industrial Processes Food and Kindred Products	2302	1.0806	Food & kindred
Industrial Processes Primary Metal Production	2303	1.0520	Primary metals
Industrial Processes Secondary Metal Production	2304	1.0520	Primary metals
Industrial Processes Mineral Processes	2305	1.0697	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	1.0844	Petroleum products
Industrial Processes Wood Products	2307	1.0798	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.1812	Rubber & plastics
Industrial Processes Fabricated Metals	2309	1.0663	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.9987	Oil & gas
Industrial Processes Construction	2311	1.0682	Construction

Description	ASC	TN	BEA Surrogate
Industrial Processes Machinery	2312	1.1875	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.0715	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.1119	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.1119	Manufacturing
Solvent Utilization Surface Coating	2401	1.1119	Manufacturing
Solvent Utilization Degreasing	2415	1.1119	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0603	Personal services
Solvent Utilization Graphic Arts	2425	1.0504	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.1812	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.1284	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.0805	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.1119	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0542	Total Population
Solvent Utilization All Solvent User Categories	2495	1.0805	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	1.0844	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	1.0077	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.0805	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.0805	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.0805	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	1.0077	Pipelines
Storage and Transport Bulk Materials Storage	2530	1.0866	Mining
Storage and Transport Bulk Materials Transport	2535	1.0866	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0542	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0542	Total Population
Waste Disposal, Treatment, and Recovery – Landfills	2620	1.0542	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0542	Total Population
Waste Disposal, Treatment, and Recovery – TSDFs	2640	1.1119	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.1119	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.1119	Manufacturing

Description	ASC	TN	BEA Surrogate
Miscellaneous Area Sources Agriculture Production – Crops	2801	1.1257	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	1.1257	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.1119	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.1119	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1051	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.1780	Business services
Miscellaneous Area Sources Health Services	2850	1.1498	Health services

Source: Developed from BEA, 1995.

Table B-7
BEA Employment Growth Factors by 4-Digit ASC for 1999 to 2007 for State of LA

Description	ASC	LA	BEA Surrogate
Stationary Source Fuel Combustion Electric Utility	2101	1.0504	Utilities
Stationary Source Fuel Combustion Industrial	2102	1.0127	Manufacturing
Stationary Source Fuel Combustion Commercial/Institutional	2103	1.0127	Manufacturing
Stationary Source Fuel Combustion Residential	2104	0.8882	Private households
Stationary Source Fuel Combustion Total Area Source Fuel Combustion	2199	1.0487	Total Population
Mobile Sources Off-highway Vehicle Gasoline 2-Stroke	2260	1.0487	Total Population
Mobile Sources Off-highway Vehicle Gasoline 4-Stroke	2265	1.0487	Total Population
Mobile Sources Off-highway Vehicle Gasoline LPG	2267	1.0487	Total Population
Mobile Sources Off-highway Vehicle Gasoline CNG	2268	1.0487	Total Population
Mobile Sources Off-highway Vehicle Gasoline Diesel	2270	1.0487	Total Population
Mobile Sources Aircraft	2275	1.0787	Transportation by air
Mobile Sources Marine Vessels	2280	0.9740	Water transportation
Mobile Sources Pleasure Craft	2282	1.0487	Total Population
Mobile Sources Railroads	2285	0.9935	Railroad transport.
Mobile Sources Paved Roads	2294	1.0932	Local & interurban
Mobile Sources Unpaved Roads	2296	1.0932	Local & interurban
Industrial Processes Chemical Manufacturing	2301	1.0322	Chemicals
Industrial Processes Food and Kindred Products	2302	1.0038	Food & kindred
Industrial Processes Primary Metal Production	2303	0.9511	Primary metals
Industrial Processes Secondary Metal Production	2304	0.9511	Primary metals
Industrial Processes Mineral Processes	2305	0.9861	Stone, clay, glass
Industrial Processes Petroleum Refining	2306	0.9521	Petroleum products
Industrial Processes Wood Products	2307	1.0106	Lumber & wood
Industrial Processes Rubber/Plastics	2308	1.2347	Rubber & plastics
Industrial Processes Fabricated Metals	2309	0.9890	Fabricated metals
Industrial Processes Oil and Gas Production	2310	0.9182	Oil & gas
Industrial Processes Construction	2311	1.0738	Construction

Description	ASC	LA	BEA Surrogate
Industrial Processes Machinery	2312	0.9981	Indust. machinery
Industrial Processes Mining and Quarrying	2325	1.0000	Nonmetallic minerals
Industrial Processes In-process Fuel Use	2390	1.0127	Manufacturing
Industrial Processes Industrial Processes: NEC	2399	1.0127	Manufacturing
Solvent Utilization Surface Coating	2401	1.0127	Manufacturing
Solvent Utilization Degreasing	2415	1.0127	Manufacturing
Solvent Utilization Dry Cleaning	2420	1.0588	Personal services
Solvent Utilization Graphic Arts	2425	1.0557	Printing & publish.
Solvent Utilization Rubber/Plastics	2430	1.2347	Rubber & plastics
Solvent Utilization Miscellaneous Industrial	2440	1.0165	Misc. manufacturing
Solvent Utilization Miscellaneous Non-industrial: All Classes	2460	1.0322	Chemicals
Solvent Utilization Miscellaneous Non-industrial: Commercial	2461	1.0127	Manufacturing
Solvent Utilization Miscellaneous Non-industrial: Consumer	2465	1.0487	Total Population
Solvent Utilization All Solvent User Categories	2495	1.0322	Chemicals
Storage and Transport Petroleum and Petroleum Product Storage	2501	0.9521	Petroleum products
Storage and Transport Petroleum and Petroleum Product Transport	2505	1.0000	Pipelines
Storage and Transport Organic Chemical Storage	2510	1.0322	Chemicals
Storage and Transport Organic Chemical Transport	2515	1.0322	Chemicals
Storage and Transport Inorganic Chemical Storage	2520	1.0322	Chemicals
Storage and Transport Inorganic Chemical Transport	2525	1.0000	Pipelines
Storage and Transport Bulk Materials Storage	2530	0.9210	Mining
Storage and Transport Bulk Materials Transport	2535	0.9210	Mining
Waste Disposal, Treatment, and Recovery - On-Site Incineration	2601	1.0487	Total Population
Waste Disposal, Treatment, and Recovery - Open Burning	2610	1.0487	Total Population
Waste Disposal, Treatment, and Recovery – Landfills	2620	1.0487	Total Population
Waste Disposal, Treatment, and Recovery - Wastewater Treatments	2630	1.0487	Total Population
Waste Disposal, Treatment, and Recovery – TSDFs	2640	1.0127	Manufacturing
Waste Disposal, Treatment, and Recovery - Scrap and Waste Materials	2650	1.0127	Manufacturing
Waste Disposal, Treatment, and Recovery - Leaking Underground Storage Tanks	2660	1.0127	Manufacturing

Description	ASC	LA	BEA Surrogate
Miscellaneous Area Sources Agriculture Production – Crops	2801	0.9463	Farm
Miscellaneous Area Sources Agriculture Production - Livestock	2805	0.9463	Farm
Miscellaneous Area Sources Cooling Towers	2820	1.0127	Manufacturing
Miscellaneous Area Sources Catastrophic/Accidental Releases	2830	1.0127	Manufacturing
Miscellaneous Area Sources Automotive Repair Shops	2840	1.1311	Auto repair & parking
Miscellaneous Area Sources Miscellaneous Repair Shops	2841	1.1965	Business services
Miscellaneous Area Sources Health Services	2850	1.1980	Health services

Source: Developed from BEA, 1995.

Table B-8
Energy Adjustment Factors applied to the Area Combustion Sources

Sector	Industry Sector	Fuel	ASC	Adjustment Factor
Industrial	Total Industrial	Steam Coal	2102001000	0.8776
Industrial	Total Industrial	Steam Coal	2102002000	0.8776
Industrial	Total Industrial	Distillate	2102004000	0.9676
Industrial	Total Industrial	Residual	2102005000	0.9654
Industrial	Total Industrial	Natural Gas	2102006000	0.9125
Industrial	Total Industrial	Natural Gas	2102006001	0.9125
Industrial	Total Industrial	Natural Gas	2102006002	0.9125
Industrial	Total Industrial	LPG	2102007000	0.9304
Industrial	Total Industrial	Renewables	2102008000	0.9575
Industrial	Total Industrial	Renewables	2102008020	0.9575
Industrial	Total Industrial	Steam Coal	2102009000	0.8776
Industrial	Total Industrial	Total Delivered Energy	2102010000	0.9229
Industrial	Total Industrial	Other Petroleum	2102011000	0.9602
Industrial	Total Industrial	Other Petroleum	2102012000	0.9602
Commercial		Coal	2103001000	0.9943
Commercial		Coal	2103002000	0.9943
Commercial		Distillate	2103004000	0.8547
Commercial		Residual	2103005000	0.9733
Commercial		Natural Gas	2103006000	0.9735
Commercial		LPG	2103007000	0.9918
Commercial		LPG	2103007005	0.9918
Commercial		LPG	2103007010	0.9918
Commercial		Renewables	2103008000	1.0389
Commercial		Kerosene	2103011000	0.9815
Commercial		Kerosene	2103011005	0.9815
Commercial		Kerosene	2103011010	0.9815
Commercial		Total Petroleum	2103012000	0.8964

Sector	Industry Sector	Fuel	ASC	Adjustment Factor
Commercial		Total Petroleum	2103012010	0.8964
Residential		Coal	2104001000	0.8379
Residential		Coal	2104002000	0.8379
Residential		Distillate	2104004000	0.764
Residential		Total Petroleum	2104005000	0.8073
Residential		Natural Gas	2104006000	0.9325
Residential		Natural Gas	2104006010	0.9325
Residential		Natural Gas	2104006020	0.9325
Residential		LPG	2104007000	0.8916
Residential		Renewables	2104008000	0.9195
Residential		Renewables	2104008001	0.9195
Residential		Renewables	2104008010	0.9195
Residential		Renewables	2104008030	0.9195
Residential		Renewables	2104008050	0.9195
Residential		Renewables	2104008051	0.9195
Residential		Renewables	2104008052	0.9195
Residential		Renewables	2104008053	0.9195
Residential		Renewables	2104008055	0.9195
Residential		Kerosene	2104011000	0.8352
Total Area		Steam Coal	2199001000	0.8765
Total Area		Steam Coal	2199002000	0.8765
Total Area		Steam Coal	2199003000	0.8765
Total Area		Distillate Oil	2199004000	0.8212
Total Area		Distillate Oil	2199004001	0.8212
Total Area		Distillate Oil	2199004002	0.8212
Total Area		Residual Oil	2199005000	0.3504
Total Area		Natural Gas	2199006000	0.9775
Total Area		Natural Gas	2199006001	0.9775
Total Area		Natural Gas	2199006002	0.9775

Sector	Industry Sector	Fuel	ASC	Adjustment Factor
Total Area		LPG	2199007000	0.9308
Total Area		Renewable Energy	2199008000	0.7416
Total Area		Metallurgical Coal	2199009000	0.707
Total Area		Natural Gas	2199010000	0.9775
Total Area		Kerosene	2199011000	0.8228
Industrial	Total Industrial	Total Coal	2390001000	0.8584
Industrial	Total Industrial	Total Coal	2390002000	0.8584
Industrial	Total Industrial	Distillate	2390004000	0.9676
Industrial	Total Industrial	Residual	2390005000	0.9654
Industrial	Total Industrial	Natural Gas	2390006000	0.9125
Industrial	Total Industrial	LPG	2390007000	0.9304
Industrial	Total Industrial	Renewables	2390008000	0.9575
Industrial	Total Industrial	Metallurgical Coal	2390009000	0.7163
Industrial	Total Industrial	Total Delivered Energy	2390010000	0.9229

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-9
Area Source VOC Control Measure Assumptions

Control Measure	Affected ASCs	VOC Percentage Reduction	VOC Rule Effectiveness
Federal Control Measures (National)			
Consumer Solvents	2465000000	25	100
Consumer Solvents	2465100000	25	100
Consumer Solvents	2465200000	25	100
Consumer Solvents	2465400000	25	100
Consumer Solvents	2465600000	25	100
Consumer Solvents	2465800000	25	100
Architectural Coatings	2401001000	25	100
Architectural Coatings	2401001999	25	100
Industrial Maintenance Coatings	2401100000	25	100
Traffic Markings	2401008000	25	100
Title III MACT (National)			
Wood Furniture Surface Coating	2401020000	30	100
Aerospace Surface Coating	2401075000	60	100
Marin Vessel Surface Coating (Shipbuilding)	2401080000	24	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415300000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415305000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415310000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415320000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415325000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415330000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415335000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415340000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415345000	43	100
Halogenated Solvent Cleaners (Cold Cleaning)	2415355000	43	100

Control Measure	Affected ASCs	VOC Percentage Reduction	VOC Rule Effectiveness
Halogenated Solvent Cleaners (Cold Cleaning)	2415360000	43	100
Autobody Refinishing	2401005000	37	100
Petroleum Refinery Fugitives	2306000000	60	100
Synthetic Organic Chemical Manufacturing Industry (SOCMI), Fugitives	2301040000	37	100
Motor Vehicle Surface Coating	2401070000	36	100
Metal Product Surface Coating	2401040000	36	100
Metal Product Surface Coating	2401045000	36	100
Metal Product Surface Coating	2401050000	36	100
Wood Product Surface Coating	2401015000	36	100
Open Top & Converyorized Degreasing	2415000000	31	100
Open Top & Converyorized Degreasing	2415105000	31	100
Open Top & Converyorized Degreasing	2415110000	31	100
Open Top & Converyorized Degreasing	2415120000	31	100
Open Top & Converyorized Degreasing	2415125000	31	100
Open Top & Converyorized Degreasing	2415130000	31	100
Open Top & Converyorized Degreasing	2415135000	31	100
Open Top & Converyorized Degreasing	2415140000	31	100
Open Top & Converyorized Degreasing	2415145000	31	100
Open Top & Converyorized Degreasing	2415199000	31	100
Open Top & Converyorized Degreasing	2415200000	31	100
Public Owned Treatment Works (POTWs)	2630000000	80	100
Public Owned Treatment Works (POTWs)	2630020000	80	100
Metal Furniture & Appliances Surface Coating	2401025000	36	100
Metal Furniture & Appliances Surface Coating	2401060000	36	100
Machinery, Railroad Surface Coating	2401550000	36	100
Machinery, Railroad Surface Coating	2401085000	36	100
Machinery, Railroad Surface Coating	2401090000	36	100

Control Measure	Affected ASCs	VOC Percentage Reduction	VOC Rule Effectiveness
Electronic Coating	2401065000	36	100
Title I RACT			
Petroleum Dry Cleaning	2420000370	44	80
Petroleum Dry Cleaning	2420010370	44	80
Paper Surface Coating	2401030000	78	80

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-10
Residential Wood Combustion Control Efficiency

Pollutant	Percent Reduction
VOC	49
CO	37

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-11
Vehicle Refueling VOC Control Efficiency

Does County Have Stage II Controls?	Percent Reduction
No	52.0
Yes	81.7

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-12
BEA Gross State Product (GSP) Growth Factors by 2-Digit SIC for 1999 to 2007 for States of AL, AR, DC, FL, GA and IA

Description	SIC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Agricultural Production - Crops	01	1.1606	1.1290	1.0000	1.1869	1.1230	1.2078	Farm
Agricultural Production - Livestock	02	1.1606	1.1290	1.0000	1.1869	1.1230	1.2078	Farm
Agricultural Services	07	1.3398	1.3488	1.4053	1.3424	1.3468	1.3201	Agricultural services
Forestry	08	1.3398	1.3488	1.4053	1.3424	1.3468	1.3201	Agricultural services
Fishing, Hunting, and Trapping	09	1.3398	1.3488	1.4053	1.3424	1.3468	1.3201	Agricultural services
Metal Mining	10	1.0848	1.1469	1.2571	1.2243	1.1613	1.0000	Metal mining
Coal mining	11	1.2396	1.3488	1.3793	1.0000	1.2000	1.2476	Coal mining
Coal Mining	12	1.2396	1.3488	1.3793	1.0000	1.2000	1.2476	Coal mining
Oil and Gas Extraction	13	0.8976	0.9770	1.1973	1.2170	1.0877	1.2444	Oil & gas
Nonmetallic Minerals except Fuels	14	1.1509	1.0973	1.1200	1.0568	1.1312	1.1195	Nonmetallic minerals
General Building Contractors	15	1.0641	1.0700	0.9885	1.1330	1.0998	1.0590	Construction
Heavy Construction	16	1.0641	1.0700	0.9885	1.1330	1.0998	1.0590	Construction
Special Trade Contractors	17	1.0641	1.0700	0.9885	1.1330	1.0998	1.0590	Construction
Food and Kindred Products	20	1.1012	1.1555	1.0461	1.1391	1.1736	1.0799	Food & kindred
Tobacco Products	21	0.7490	1.0000	1.0000	0.6957	0.8759	1.0000	Tobacco products
Textile Mill Products	22	1.1344	1.0866	1.1310	1.1131	1.1126	1.0776	Textile mill prod.
Apparel and Other Textile Products	23	1.1461	1.1703	1.0000	1.1595	1.1280	1.1852	Apparel & textile
Lumber and Wood Products	24	1.0844	1.0551	0.8889	1.0377	1.0512	1.1294	Lumber & wood
Furniture and Fixtures	25	1.1524	1.1161	1.1385	1.1076	1.0830	1.1432	Furniture
Paper and Allied Products	26	1.1604	1.1840	1.2800	1.1022	1.1925	1.1748	Paper products
Printing and Publishing	27	1.0638	1.0285	1.0137	1.1267	1.1070	1.0263	Printing & publish.
Chemical and Allied Products	28	1.1011	1.0853	1.0905	1.0500	1.1441	1.0713	Chemicals
Petroleum and Coal Products	29	1.1341	1.0953	1.0710	1.1260	1.0486	0.8908	Petroleum products
Rubber and Misc. Plastic Products	30	1.2464	1.2790	1.4000	1.2663	1.2371	1.2426	Rubber & plastics
Leather and Leather Products	31	0.9419	0.9677	2.1429	0.9974	1.0154	1.0220	Leather products
Stone, Clay and Glass Products	32	1.0499	1.0924	1.0946	1.0915	1.0902	1.0809	Stone, clay, glass
Primary Metal Industries	33	1.0281	1.1179	1.0000	1.0501	1.0096	1.0511	Primary metals

Description	SIC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Fabricated Metal Industries	34	1.0553	1.0918	0.8909	0.9934	1.0835	1.0605	Fabricated metals
Industrial Machinery and Equipment	35	1.3388	1.3579	1.2310	1.2431	1.3379	1.1995	Indust. machinery
Electronic and Other Electronic Equipment	36	1.2975	1.1730	1.1204	1.1787	1.2212	1.1569	Electronic equip.
Transportation Equipment	37	1.2827	1.3111	1.1793	1.2887	1.2944	1.3412	Other trans. equip.
Instruments and Related Products	38	1.1535	1.0635	1.0303	1.2466	1.3599	1.1341	Instruments
Misc. Manufacturing Industries	39	1.1552	1.1660	1.0937	1.2140	1.1532	1.1411	Misc. manufacturing
Railroad Transportation	40	1.2486	1.2560	1.3588	1.3145	1.2397	1.2412	Railroad transport.
Local and Interurban Passenger Transit	41	1.1402	1.1470	1.0190	1.2010	1.1771	1.0724	Local & interurban
Trucking and Warehousing	42	1.2046	1.2131	1.0697	1.2351	1.2246	1.1502	Trucking
Water Transportation	44	1.0134	1.0884	1.0253	1.1198	1.0346	1.1184	Water transportation
Transportation by Air	45	1.3337	1.2875	1.2173	1.2628	1.2298	1.2728	Transportation by air
Pipelines except Natural Gas	46	0.9872	1.0542	1.0959	1.2511	1.1358	0.9638	Pipelines
Transportation Services	47	1.2746	1.2510	1.1808	1.3012	1.3699	1.1768	Transport. services
Communications	48	1.2098	1.2153	1.1043	1.2694	1.2878	1.1827	Communications
Electric, Gas, and Sanitary Services	49	1.1679	1.1586	1.1014	1.2174	1.2013	1.1116	Utilities
Wholesale Trade - Durable Goods	50	1.1830	1.1797	1.0746	1.2665	1.2202	1.1498	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1830	1.1797	1.0746	1.2665	1.2202	1.1498	Wholesale trade
Building Materials & Garden Supplies	52	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
General Merchandise Stores	53	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Food Stores	54	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Automotive Dealers & Service Stations	55	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Apparel and Accessory Stores	56	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Furniture and Homefurnishing Stores	57	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Eating and Drinking Places	58	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Misc. Retail	59	1.1478	1.1479	1.0638	1.2126	1.1864	1.1171	Retail trade
Depository Institutions	60	1.2158	1.2019	1.1306	1.2543	1.2600	1.1595	Banks & investment
Nondepository Institutions	61	1.2158	1.2019	1.1306	1.2543	1.2600	1.1595	Banks & investment
Security and Commodity Brokers	62	1.2158	1.2019	1.1306	1.2543	1.2600	1.1595	Banks & investment
Insurance Carriers	63	1.1382	1.1561	1.0252	1.2222	1.2091	1.1772	Insurance

Description	SIC	AL	AR	DC	FL	GA	IA	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1382	1.1561	1.0252	1.2222	1.2091	1.1772	Insurance
Real Estate	65	1.1540	1.1525	1.1226	1.2211	1.2002	1.1342	Real estate
Holding and Other Investment Offices	67	1.2158	1.2019	1.1306	1.2543	1.2600	1.1595	Banks & investment
Hotels and Other Lodging Places	70	1.1349	1.1470	1.1705	1.2078	1.2052	1.1227	Hotels & lodging
Personal Services	72	1.0876	1.0697	1.0041	1.1306	1.1109	1.0474	Personal services
Business Services	73	1.2586	1.2240	1.1429	1.2917	1.2753	1.2052	Business services
Auto Repair, Services, and Parking	75	1.1339	1.1158	1.0396	1.1694	1.1749	1.1045	Auto repair & parking
Misc. Repair Services	76	1.2586	1.2240	1.1429	1.2917	1.2753	1.2052	Business services
Motion Pictures	78	1.2308	1.1967	1.1333	1.2453	1.2792	1.1932	Amusement
Amusement & Recreation Services	79	1.2308	1.1967	1.1333	1.2453	1.2792	1.1932	Amusement
Health Services	80	1.1922	1.1833	1.1405	1.2588	1.2768	1.1432	Health services
Legal Services	81	1.1530	1.1070	1.1177	1.1676	1.1770	1.0722	Legal services
Educational Services	82	1.1264	1.1501	1.1222	1.2039	1.2129	1.1123	Educational services
Social Services	83	1.2199	1.2079	1.1682	1.3098	1.2613	1.1945	Social services
Museums, Botanical, Zoological Gardens	84	1.2317	1.2028	1.2220	1.2920	1.2814	1.1982	Other services
Membership Organizations	86	1.2199	1.2079	1.1682	1.3098	1.2613	1.1945	Social services
Engineering & Management Services	87	1.2317	1.2028	1.2220	1.2920	1.2814	1.1982	Other services
Private Households	88	1.0209	1.0274	0.9972	1.0808	1.0662	1.0143	Private households
Services, NEC	89	1.2317	1.2028	1.2220	1.2920	1.2814	1.1982	Other services
Executive, Legislative, and General	91	1.0538	1.0787	0.9951	1.1461	1.1061	1.0455	Government
Justice, Public Order, and Safety	92	1.0955	1.1004	1.0321	1.1738	1.1413	1.0569	State and local
Finance, Taxation, & Monetary Policy	93	1.0955	1.1004	1.0321	1.1738	1.1413	1.0569	State and local
Administration of Human Resources	94	1.0955	1.1004	1.0321	1.1738	1.1413	1.0569	State and local
Environmental Quality and Housing	95	1.0955	1.1004	1.0321	1.1738	1.1413	1.0569	State and local
Administration of Economic Programs	96	1.0955	1.1004	1.0321	1.1738	1.1413	1.0569	State and local
National Security and International Affairs	97	1.0538	1.0787	0.9951	1.1461	1.1061	1.0455	Government

Source: Developed from BEA, 1995.

Table B-13
BEA Gross State Product (GSP) Growth Factors by 2-Digit SIC for 1999 to 2007 for States of IL, IN, KS, KY, MD and MI

Description	SIC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Agricultural Production - Crops	01	1.1186	1.1904	1.1337	1.2015	1.1518	1.1599	Farm
Agricultural Production - Livestock	02	1.1186	1.1904	1.1337	1.2015	1.1518	1.1599	Farm
Agricultural Services	07	1.3465	1.3648	1.3687	1.3540	1.3286	1.3447	Agricultural services
Forestry	08	1.3465	1.3648	1.3687	1.3540	1.3286	1.3447	Agricultural services
Fishing, Hunting, and Trapping	09	1.3465	1.3648	1.3687	1.3540	1.3286	1.3447	Agricultural services
Metal Mining	10	1.3451	1.1667	1.0000	1.2571	1.3185	1.2127	Metal mining
Coal mining	11	1.2229	1.1975	1.1539	1.2275	1.2897	1.2571	Coal mining
Coal Mining	12	1.2229	1.1975	1.1539	1.2275	1.2897	1.2571	Coal mining
Oil and Gas Extraction	13	0.8898	0.9427	0.9703	0.9545	1.0000	0.9467	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0620	1.0860	1.0982	1.1293	1.0725	1.1041	Nonmetallic minerals
General Building Contractors	15	1.0644	1.0653	1.0585	1.0635	1.0507	1.0531	Construction
Heavy Construction	16	1.0644	1.0653	1.0585	1.0635	1.0507	1.0531	Construction
Special Trade Contractors	17	1.0644	1.0653	1.0585	1.0635	1.0507	1.0531	Construction
Food and Kindred Products	20	1.0599	1.0679	1.1307	1.0571	1.0084	1.0613	Food & kindred
Tobacco Products	21	0.7481	0.8000	1.0000	0.7631	1.0000	1.0000	Tobacco products
Textile Mill Products	22	1.0757	1.2100	1.1241	1.1366	1.1281	1.0381	Textile mill prod.
Apparel and Other Textile Products	23	1.1129	1.1600	1.1846	1.2364	1.0005	1.0722	Apparel & textile
Lumber and Wood Products	24	1.0338	1.1148	1.0720	1.1221	1.0629	1.0748	Lumber & wood
Furniture and Fixtures	25	1.1155	1.1352	1.0308	1.0773	1.1031	1.1153	Furniture
Paper and Allied Products	26	1.1615	1.2006	1.1903	1.2924	1.0620	1.1406	Paper products
Printing and Publishing	27	1.0365	1.0454	1.0769	1.0303	1.0690	1.0290	Printing & publish.
Chemical and Allied Products	28	1.1349	1.1339	1.0829	1.1089	1.1170	1.1285	Chemicals
Petroleum and Coal Products	29	1.0719	1.1224	1.0982	1.1282	1.1523	1.0652	Petroleum products
Rubber and Misc. Plastic Products	30	1.2330	1.2656	1.2691	1.2341	1.1520	1.2866	Rubber & plastics
Leather and Leather Products	31	0.9825	0.9756	1.1172	0.9167	0.9775	1.0124	Leather products
Stone, Clay and Glass Products	32	1.0273	1.0512	1.0284	1.1232	0.9985	1.0684	Stone, clay, glass
Primary Metal Industries	33	0.9951	1.0348	1.0696	1.0555	0.9017	1.0000	Primary metals

Description	SIC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Fabricated Metal Industries	34	1.0068	1.0527	1.0311	1.1467	1.0111	1.0418	Fabricated metals
Industrial Machinery and Equipment	35	1.2091	1.2546	1.2382	1.2140	1.2043	1.2220	Indust. machinery
Electronic and Other Electronic Equipment	36	1.1660	1.1600	1.2069	1.1320	1.1168	1.1467	Electronic equip.
Transportation Equipment	37	1.1509	1.1311	1.2020	1.3220	1.0749	1.2440	Other trans. equip.
Instruments and Related Products	38	1.0521	1.2024	1.0983	1.1220	1.1036	1.1425	Instruments
Misc. Manufacturing Industries	39	1.1066	1.1436	1.1123	1.1487	1.0661	1.1159	Misc. manufacturing
Railroad Transportation	40	1.2087	1.2585	1.2513	1.1765	1.0927	1.1821	Railroad transport.
Local and Interurban Passenger Transit	41	1.1307	1.1251	1.1228	1.1175	1.1187	1.0822	Local & interurban
Trucking and Warehousing	42	1.1329	1.1855	1.1508	1.1755	1.1571	1.1057	Trucking
Water Transportation	44	1.0538	1.1012	1.0905	1.0153	0.9617	1.0681	Water transportation
Transportation by Air	45	1.2683	1.3536	1.3029	1.3120	1.3482	1.2258	Transportation by air
Pipelines except Natural Gas	46	1.0193	1.0203	1.1442	1.0472	1.0641	1.0820	Pipelines
Transportation Services	47	1.2166	1.2251	1.2175	1.2594	1.2508	1.2376	Transport. services
Communications	48	1.2085	1.2130	1.2229	1.2023	1.2160	1.1638	Communications
Electric, Gas, and Sanitary Services	49	1.1223	1.1304	1.1614	1.1173	1.1583	1.1179	Utilities
Wholesale Trade - Durable Goods	50	1.1643	1.2036	1.1754	1.1662	1.1864	1.1594	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1643	1.2036	1.1754	1.1662	1.1864	1.1594	Wholesale trade
Building Materials & Garden Supplies	52	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
General Merchandise Stores	53	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Food Stores	54	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Automotive Dealers & Service Stations	55	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Apparel and Accessory Stores	56	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Furniture and Homefurnishing Stores	57	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Eating and Drinking Places	58	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Misc. Retail	59	1.1423	1.1425	1.1599	1.1529	1.1521	1.1191	Retail trade
Depository Institutions	60	1.2072	1.2063	1.1731	1.1850	1.2123	1.1825	Banks & investment
Nondepository Institutions	61	1.2072	1.2063	1.1731	1.1850	1.2123	1.1825	Banks & investment
Security and Commodity Brokers	62	1.2072	1.2063	1.1731	1.1850	1.2123	1.1825	Banks & investment
Insurance Carriers	63	1.1700	1.1703	1.1593	1.1659	1.1716	1.1371	Insurance

Description	SIC	IL	IN	KS	KY	MD	MI	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1700	1.1703	1.1593	1.1659	1.1716	1.1371	Insurance
Real Estate	65	1.1467	1.1592	1.1500	1.1320	1.1683	1.1471	Real estate
Holding and Other Investment Offices	67	1.2072	1.2063	1.1731	1.1850	1.2123	1.1825	Banks & investment
Hotels and Other Lodging Places	70	1.1376	1.1351	1.1236	1.1574	1.2330	1.1227	Hotels & lodging
Personal Services	72	1.0669	1.0690	1.0792	1.0613	1.0699	1.0532	Personal services
Business Services	73	1.1915	1.2290	1.2382	1.2596	1.2166	1.2031	Business services
Auto Repair, Services, and Parking	75	1.1253	1.1182	1.1437	1.1338	1.1425	1.1028	Auto repair & parking
Misc. Repair Services	76	1.1915	1.2290	1.2382	1.2596	1.2166	1.2031	Business services
Motion Pictures	78	1.2155	1.2190	1.2246	1.1770	1.2357	1.1942	Amusement
Amusement & Recreation Services	79	1.2155	1.2190	1.2246	1.1770	1.2357	1.1942	Amusement
Health Services	80	1.1738	1.1811	1.1762	1.1874	1.2034	1.1492	Health services
Legal Services	81	1.1032	1.1320	1.0939	1.1053	1.1337	1.0849	Legal services
Educational Services	82	1.1329	1.1452	1.1668	1.1600	1.1582	1.1266	Educational services
Social Services	83	1.2192	1.2115	1.2320	1.1866	1.2360	1.1929	Social services
Museums, Botanical, Zoological Gardens	84	1.2272	1.2296	1.2447	1.2098	1.2228	1.1661	Other services
Membership Organizations	86	1.2192	1.2115	1.2320	1.1866	1.2360	1.1929	Social services
Engineering & Management Services	87	1.2272	1.2296	1.2447	1.2098	1.2228	1.1661	Other services
Private Households	88	1.0503	1.0409	1.0574	1.0293	1.0562	1.0325	Private households
Services, NEC	89	1.2272	1.2296	1.2447	1.2098	1.2228	1.1661	Other services
Executive, Legislative, and General	91	1.0720	1.0851	1.0892	1.0727	1.0580	1.0561	Government
Justice, Public Order, and Safety	92	1.0877	1.1012	1.1122	1.1040	1.1001	1.0644	State and local
Finance, Taxation, & Monetary Policy	93	1.0877	1.1012	1.1122	1.1040	1.1001	1.0644	State and local
Administration of Human Resources	94	1.0877	1.1012	1.1122	1.1040	1.1001	1.0644	State and local
Environmental Quality and Housing	95	1.0877	1.1012	1.1122	1.1040	1.1001	1.0644	State and local
Administration of Economic Programs	96	1.0877	1.1012	1.1122	1.1040	1.1001	1.0644	State and local
National Security and International Affairs	97	1.0720	1.0851	1.0892	1.0727	1.0580	1.0561	Government

Source: Developed from BEA, 1995.

Table B-14
BEA Gross State Product (GSP) Growth factors by 2-Digit SIC for 1999 to 2007 for States MO, MS, NC, NE, NY and OH

Description	SIC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Agricultural Production - Crops	01	1.1838	1.1442	1.1009	1.1333	1.1740	1.1656	Farm
Agricultural Production - Livestock	02	1.1838	1.1442	1.1009	1.1333	1.1740	1.1656	Farm
Agricultural Services	07	1.3277	1.3320	1.3477	1.3364	1.2568	1.3371	Agricultural services
Forestry	08	1.3277	1.3320	1.3477	1.3364	1.2568	1.3371	Agricultural services
Fishing, Hunting, and Trapping	09	1.3277	1.3320	1.3477	1.3364	1.2568	1.3371	Agricultural services
Metal Mining	10	1.1439	1.0000	1.1535	1.2379	1.1922	1.3516	Metal mining
Coal mining	11	1.1756	1.0000	2.0000	1.0000	1.0000	1.1591	Coal mining
Coal Mining	12	1.1756	1.0000	2.0000	1.0000	1.0000	1.1591	Coal mining
Oil and Gas Extraction	13	0.9812	1.0061	1.1133	0.9119	0.9995	0.9485	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0734	1.1073	1.1042	1.1175	1.0868	1.0931	Nonmetallic minerals
General Building Contractors	15	1.0536	1.0784	1.1117	1.0902	1.0205	1.0663	Construction
Heavy Construction	16	1.0536	1.0784	1.1117	1.0902	1.0205	1.0663	Construction
Special Trade Contractors	17	1.0536	1.0784	1.1117	1.0902	1.0205	1.0663	Construction
Food and Kindred Products	20	1.1039	1.1235	1.1249	1.0876	1.0091	1.0903	Food & kindred
Tobacco Products	21	0.8571	1.0000	0.7798	1.0000	0.7542	0.8000	Tobacco products
Textile Mill Products	22	1.0656	1.1743	1.0775	1.0182	0.9691	1.0729	Textile mill prod.
Apparel and Other Textile Products	23	1.1209	1.1535	1.1398	1.1714	1.0326	1.1016	Apparel & textile
Lumber and Wood Products	24	1.0776	1.0716	1.1054	1.0581	1.0364	1.1239	Lumber & wood
Furniture and Fixtures	25	1.1265	1.1680	1.0993	1.1472	1.0152	1.0983	Furniture
Paper and Allied Products	26	1.1571	1.1760	1.2154	1.1994	1.0489	1.1371	Paper products
Printing and Publishing	27	1.0487	1.0805	1.1131	1.0408	0.9719	1.0174	Printing & publish.
Chemical and Allied Products	28	1.1267	1.1060	1.1903	1.1352	1.0696	1.1175	Chemicals
Petroleum and Coal Products	29	1.1247	1.1112	1.1804	1.1833	1.0508	1.1216	Petroleum products
Rubber and Misc. Plastic Products	30	1.2550	1.3197	1.2759	1.2416	1.2018	1.1797	Rubber & plastics
Leather and Leather Products	31	0.9638	0.9884	0.9910	1.2022	0.8540	0.9880	Leather products
Stone, Clay and Glass Products	32	1.0569	1.0597	1.1164	1.0740	1.0454	1.0375	Stone, clay, glass
Primary Metal Industries	33	1.0165	1.0810	1.1158	1.0645	0.8853	1.0142	Primary metals

Description	SIC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Fabricated Metal Industries	34	1.0739	1.0548	1.1251	1.0456	0.9689	1.0291	Fabricated metals
Industrial Machinery and Equipment	35	1.2346	1.3359	1.2821	1.2307	1.0931	1.2235	Indust. Machinery
Electronic and Other Electronic Equipment	36	1.1196	1.2028	1.2176	1.1578	1.0392	1.1569	Electronic equip.
Transportation Equipment	37	1.1720	1.2350	1.2975	1.2092	1.0287	1.1992	Other trans. equip.
Instruments and Related Products	38	1.1343	1.1578	1.2148	1.1624	1.0345	1.1528	Instruments
Misc. Manufacturing Industries	39	1.1269	1.1150	1.2243	1.1042	1.0639	1.1450	Misc. manufacturing
Railroad Transportation	40	1.2531	1.2256	1.1963	1.2771	1.2004	1.1598	Railroad transport.
Local and Interurban Passenger Transit	41	1.1214	1.0994	1.0441	1.1282	1.0796	1.1258	Local & interurban
Trucking and Warehousing	42	1.1564	1.1881	1.1754	1.1862	1.1081	1.1202	Trucking
Water Transportation	44	0.8802	1.0072	1.0668	1.0492	0.8598	1.0281	Water transportation
Transportation by Air	45	1.1542	1.3505	1.2937	1.2788	1.1465	1.2588	Transportation by air
Pipelines except Natural Gas	46	0.9943	1.0620	1.0842	1.0337	1.0638	1.0413	Pipelines
Transportation Services	47	1.2202	1.1821	1.2936	1.1644	1.1048	1.2529	Transport. services
Communications	48	1.2452	1.2095	1.2602	1.2068	1.1737	1.1630	Communications
Electric, Gas, and Sanitary Services	49	1.1258	1.1566	1.1674	1.1497	1.1116	1.1141	Utilities
Wholesale Trade - Durable Goods	50	1.1693	1.1731	1.2162	1.1852	1.1343	1.1623	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1693	1.1731	1.2162	1.1852	1.1343	1.1623	Wholesale trade
Building Materials & Garden Supplies	52	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
General Merchandise Stores	53	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Food Stores	54	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Automotive Dealers & Service Stations	55	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Apparel and Accessory Stores	56	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Furniture and Homefurnishing Stores	57	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Eating and Drinking Places	58	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Misc. Retail	59	1.1480	1.1461	1.1728	1.1546	1.1079	1.1301	Retail trade
Depository Institutions	60	1.2018	1.1915	1.2944	1.2268	1.1749	1.2026	Banks & investment
Nondepository Institutions	61	1.2018	1.1915	1.2944	1.2268	1.1749	1.2026	Banks & investment
Security and Commodity Brokers	62	1.2018	1.1915	1.2944	1.2268	1.1749	1.2026	Banks & investment
Insurance Carriers	63	1.1508	1.1475	1.1838	1.1594	1.1107	1.1408	Insurance

Description	SIC	MO	MS	NC	NE	NY	OH	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1508	1.1475	1.1838	1.1594	1.1107	1.1408	Insurance
Real Estate	65	1.1653	1.1525	1.2123	1.1503	1.1154	1.1381	Real estate
Holding and Other Investment Offices	67	1.2018	1.1915	1.2944	1.2268	1.1749	1.2026	Banks & investment
Hotels and Other Lodging Places	70	1.1924	1.1422	1.2025	1.1409	1.1020	1.1222	Hotels & lodging
Personal Services	72	1.0717	1.0736	1.0916	1.0673	1.0224	1.0585	Personal services
Business Services	73	1.2129	1.2399	1.2951	1.2218	1.1224	1.1994	Business services
Auto Repair, Services, and Parking	75	1.1233	1.1214	1.1704	1.1245	1.0582	1.1192	Auto repair & parking
Misc. Repair Services	76	1.2129	1.2399	1.2951	1.2218	1.1224	1.1994	Business services
Motion Pictures	78	1.2126	1.3176	1.3022	1.2071	1.1635	1.1948	Amusement
Amusement & Recreation Services	79	1.2126	1.3176	1.3022	1.2071	1.1635	1.1948	Amusement
Health Services	80	1.1763	1.1992	1.2619	1.1721	1.1614	1.1590	Health services
Legal Services	81	1.1202	1.1046	1.1972	1.0837	1.0802	1.1033	Legal services
Educational Services	82	1.1526	1.1261	1.1372	1.1579	1.1170	1.1249	Educational services
Social Services	83	1.2106	1.1908	1.2686	1.2038	1.1898	1.1931	Social services
Museums, Botanical, Zoological Gardens	84	1.2245	1.2110	1.2697	1.2410	1.1427	1.1886	Other services
Membership Organizations	86	1.2106	1.1908	1.2686	1.2038	1.1898	1.1931	Social services
Engineering & Management Services	87	1.2245	1.2110	1.2697	1.2410	1.1427	1.1886	Other services
Private Households	88	1.0395	1.0280	1.0750	1.0446	1.0353	1.0105	Private households
Services, NEC	89	1.2245	1.2110	1.2697	1.2410	1.1427	1.1886	Other services
Executive, Legislative, and General	91	1.0720	1.0605	1.1031	1.0790	1.0508	1.0687	Government
Justice, Public Order, and Safety	92	1.0976	1.0811	1.1297	1.0966	1.0586	1.0840	State and local
Finance, Taxation, & Monetary Policy	93	1.0976	1.0811	1.1297	1.0966	1.0586	1.0840	State and local
Administration of Human Resources	94	1.0976	1.0811	1.1297	1.0966	1.0586	1.0840	State and local
Environmental Quality and Housing	95	1.0976	1.0811	1.1297	1.0966	1.0586	1.0840	State and local
Administration of Economic Programs	96	1.0976	1.0811	1.1297	1.0966	1.0586	1.0840	State and local
National Security and International Affairs	97	1.0720	1.0605	1.1031	1.0790	1.0508	1.0687	Government

Source: Developed from BEA, 1995.

Table B-15
BEA Gross State Product (GSP) Growth factors by 2-Digit SIC for 1999 to 2007 for States OK, PA, SC, TN, VA and WV

Description	SIC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Agricultural Production - Crops	01	1.1973	1.1697	1.1338	1.1853	1.1052	1.2984	Farm
Agricultural Production - Livestock	02	1.1973	1.1697	1.1338	1.1853	1.1052	1.2984	Farm
Agricultural Services	07	1.4006	1.3071	1.3304	1.3550	1.3446	1.3907	Agricultural services
Forestry	08	1.4006	1.3071	1.3304	1.3550	1.3446	1.3907	Agricultural services
Fishing, Hunting, and Trapping	09	1.4006	1.3071	1.3304	1.3550	1.3446	1.3907	Agricultural services
Metal Mining	10	1.3450	0.8571	1.2533	1.2684	1.1404	1.3206	Metal mining
Coal mining	11	1.2200	1.1296	1.2218	1.0382	1.2085	1.1396	Coal mining
Coal Mining	12	1.2200	1.1296	1.2218	1.0382	1.2085	1.1396	Coal mining
Oil and Gas Extraction	13	0.9568	1.0256	1.0050	1.0034	1.0902	0.9336	Oil & gas
Nonmetallic Minerals except Fuels	14	1.1151	1.1185	1.1339	1.1007	1.1064	1.0776	Nonmetallic minerals
General Building Contractors	15	1.0876	1.0364	1.1247	1.0918	1.0907	1.0369	Construction
Heavy Construction	16	1.0876	1.0364	1.1247	1.0918	1.0907	1.0369	Construction
Special Trade Contractors	17	1.0876	1.0364	1.1247	1.0918	1.0907	1.0369	Construction
Food and Kindred Products	20	1.0977	1.0645	1.1234	1.1118	1.1256	1.0518	Food & kindred
Tobacco Products	21	1.0000	0.6822	0.6278	0.8146	0.7847	0.7938	Tobacco products
Textile Mill Products	22	1.0433	0.9391	1.0566	1.0766	1.0911	1.1751	Textile mill prod.
Apparel and Other Textile Products	23	1.0783	0.9637	1.1020	1.1447	1.1293	1.0825	Apparel & textile
Lumber and Wood Products	24	1.0845	1.0979	1.0506	1.1064	1.0914	1.1425	Lumber & wood
Furniture and Fixtures	25	1.1098	1.0416	1.1394	1.1531	1.0895	1.0451	Furniture
Paper and Allied Products	26	1.2170	1.1133	1.2483	1.2018	1.1437	1.1218	Paper products
Printing and Publishing	27	1.0001	1.0376	1.1019	1.0689	1.0952	1.0263	Printing & publish.
Chemical and Allied Products	28	1.1097	1.1212	1.1650	1.1076	1.0783	1.0490	Chemicals
Petroleum and Coal Products	29	1.1152	1.0415	1.2691	1.1205	1.1811	1.0816	Petroleum products
Rubber and Misc. Plastic Products	30	1.2588	1.2144	1.2557	1.2579	1.2693	1.3066	Rubber & plastics
Leather and Leather Products	31	0.9858	0.9208	0.7818	0.9658	0.9601	0.9807	Leather products
Stone, Clay and Glass Products	32	1.0674	1.0178	1.0620	1.0911	1.0452	1.0237	Stone, clay, glass
Primary Metal Industries	33	1.0935	0.8953	1.1596	1.0676	1.0486	1.0062	Primary metals

Description	SIC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Fabricated Metal Industries	34	1.1199	1.0018	1.1633	1.0876	1.0470	1.0878	Fabricated metals
Industrial Machinery and Equipment	35	1.2321	1.1928	1.3869	1.2828	1.3207	1.1821	Indust. Machinery
Electronic and Other Electronic Equipment	36	1.1500	1.0474	1.2846	1.1973	1.1711	1.0549	Electronic equip.
Transportation Equipment	37	1.1989	1.2184	1.2855	1.2398	1.2117	1.2976	Other trans. equip.
Instruments and Related Products	38	1.2928	1.0450	1.1819	1.1650	1.1338	1.1780	Instruments
Misc. Manufacturing Industries	39	1.1913	1.0798	1.1400	1.1732	1.1310	1.1600	Misc. manufacturing
Railroad Transportation	40	1.2016	1.2162	1.2214	1.2237	1.2718	1.2173	Railroad transport.
Local and Interurban Passenger Transit	41	1.0939	1.1260	1.1236	1.1311	1.1093	1.0957	Local & interurban
Trucking and Warehousing	42	1.1519	1.1134	1.2292	1.1895	1.1820	1.1466	Trucking
Water Transportation	44	1.1059	0.9851	1.0546	1.0878	1.0326	1.0177	Water transportation
Transportation by Air	45	1.2662	1.2724	1.3697	1.3352	1.2586	1.2461	Transportation by air
Pipelines except Natural Gas	46	1.0374	1.0231	1.0126	1.0281	1.0341	0.9996	Pipelines
Transportation Services	47	1.2606	1.1914	1.2610	1.2705	1.2603	1.2906	Transport. services
Communications	48	1.2234	1.1927	1.2485	1.2408	1.2420	1.1866	Communications
Electric, Gas, and Sanitary Services	49	1.1421	1.1179	1.1636	1.2014	1.1715	1.1338	Utilities
Wholesale Trade - Durable Goods	50	1.1705	1.1588	1.2271	1.1968	1.2035	1.1473	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1705	1.1588	1.2271	1.1968	1.2035	1.1473	Wholesale trade
Building Materials & Garden Supplies	52	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
General Merchandise Stores	53	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Food Stores	54	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Automotive Dealers & Service Stations	55	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Apparel and Accessory Stores	56	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Furniture and Homefurnishing Stores	57	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Eating and Drinking Places	58	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Misc. Retail	59	1.1401	1.1222	1.1791	1.1624	1.1621	1.1275	Retail trade
Depository Institutions	60	1.1689	1.1891	1.2523	1.2333	1.2679	1.1565	Banks & investment
Nondepository Institutions	61	1.1689	1.1891	1.2523	1.2333	1.2679	1.1565	Banks & investment
Security and Commodity Brokers	62	1.1689	1.1891	1.2523	1.2333	1.2679	1.1565	Banks & investment
Insurance Carriers	63	1.1432	1.1660	1.1667	1.1655	1.1962	1.1125	Insurance

Description	SIC	OK	PA	SC	TN	VA	WV	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1432	1.1660	1.1667	1.1655	1.1962	1.1125	Insurance
Real Estate	65	1.1366	1.1291	1.2134	1.1733	1.1865	1.1314	Real estate
Holding and Other Investment Offices	67	1.1689	1.1891	1.2523	1.2333	1.2679	1.1565	Banks & investment
Hotels and Other Lodging Places	70	1.0896	1.1279	1.2137	1.1889	1.1841	1.1624	Hotels & lodging
Personal Services	72	1.0786	1.0431	1.1087	1.0826	1.0842	1.0393	Personal services
Business Services	73	1.2037	1.1789	1.2934	1.2658	1.2435	1.2511	Business services
Auto Repair, Services, and Parking	75	1.1351	1.0974	1.1629	1.1513	1.1412	1.1134	Auto repair & parking
Misc. Repair Services	76	1.2037	1.1789	1.2934	1.2658	1.2435	1.2511	Business services
Motion Pictures	78	1.1989	1.1747	1.2809	1.2545	1.2452	1.1635	Amusement
Amusement & Recreation Services	79	1.1989	1.1747	1.2809	1.2545	1.2452	1.1635	Amusement
Health Services	80	1.1790	1.1822	1.2648	1.2051	1.2093	1.1628	Health services
Legal Services	81	1.1013	1.1151	1.1867	1.1378	1.1405	1.1099	Legal services
Educational Services	82	1.1286	1.1313	1.1444	1.1696	1.1709	1.1641	Educational services
Social Services	83	1.2103	1.2266	1.2622	1.2380	1.2337	1.1970	Social services
Museums, Botanical, Zoological Gardens	84	1.1791	1.1896	1.2894	1.2731	1.2590	1.2294	Other services
Membership Organizations	86	1.2103	1.2266	1.2622	1.2380	1.2337	1.1970	Social services
Engineering & Management Services	87	1.1791	1.1896	1.2894	1.2731	1.2590	1.2294	Other services
Private Households	88	1.0432	1.0193	1.0603	1.0551	1.0519	1.0229	Private households
Services, NEC	89	1.1791	1.1896	1.2894	1.2731	1.2590	1.2294	Other services
Executive, Legislative, and General	91	1.0581	1.0508	1.1118	1.0878	1.0677	1.0681	Government
Justice, Public Order, and Safety	92	1.0867	1.0679	1.1436	1.1223	1.1144	1.0759	State and local
Finance, Taxation, & Monetary Policy	93	1.0867	1.0679	1.1436	1.1223	1.1144	1.0759	State and local
Administration of Human Resources	94	1.0867	1.0679	1.1436	1.1223	1.1144	1.0759	State and local
Environmental Quality and Housing	95	1.0867	1.0679	1.1436	1.1223	1.1144	1.0759	State and local
Administration of Economic Programs	96	1.0867	1.0679	1.1436	1.1223	1.1144	1.0759	State and local
National Security and International Affairs	97	1.0581	1.0508	1.1118	1.0878	1.0677	1.0681	Government

Source: Developed from BEA, 1995.

Table B-16
BEA Gross State Product (GSP) Growth factors by 2-Digit SIC for 2001 to 2007 for State of MS

Description	SIC	MS	BEA Surrogate
Agricultural Production - Crops	01	1.1102	Farm
Agricultural Production - Livestock	02	1.1102	Farm
Agricultural Services	07	1.2346	Agricultural services
Forestry	08	1.2346	Agricultural services
Fishing, Hunting, and Trapping	09	1.2346	Agricultural services
Metal Mining	10	1.0000	Metal mining
Coal mining	11	1.0000	Coal mining
Coal Mining	12	1.0000	Coal mining
Oil and Gas Extraction	13	0.9991	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0727	Nonmetallic minerals
General Building Contractors	15	1.0642	Construction
Heavy Construction	16	1.0642	Construction
Special Trade Contractors	17	1.0642	Construction
Food and Kindred Products	20	1.0894	Food & kindred
Tobacco Products	21	1.0000	Tobacco products
Textile Mill Products	22	1.1212	Textile mill prod.
Apparel and Other Textile Products	23	1.1094	Apparel & textile
Lumber and Wood Products	24	1.0581	Lumber & wood
Furniture and Fixtures	25	1.1238	Furniture
Paper and Allied Products	26	1.1267	Paper products
Printing and Publishing	27	1.0603	Printing & publish.
Chemical and Allied Products	28	1.0795	Chemicals
Petroleum and Coal Products	29	1.0833	Petroleum products
Rubber and Misc. Plastic Products	30	1.2220	Rubber & plastics
Leather and Leather Products	31	0.9846	Leather products
Stone, Clay and Glass Products	32	1.0495	Stone, clay, glass
Primary Metal Industries	33	1.0623	Primary metals

Description	SIC	MS	BEA Surrogate
Fabricated Metal Industries	34	1.0471	Fabricated metals
Industrial Machinery and Equipment	35	1.2251	Indust. machinery
Electronic and Other Electronic Equipment	36	1.1424	Electronic equip.
Transportation Equipment	37	1.1615	Other trans. equip.
Instruments and Related Products	38	1.1203	Instruments
Misc. Manufacturing Industries	39	1.0871	Misc. manufacturing
Railroad Transportation	40	1.1539	Railroad transport.
Local and Interurban Passenger Transit	41	1.0673	Local & interurban
Trucking and Warehousing	42	1.1353	Trucking
Water Transportation	44	1.0070	Water transportation
Transportation by Air	45	1.2343	Transportation by air
Pipelines except Natural Gas	46	1.0337	Pipelines
Transportation Services	47	1.1265	Transport. services
Communications	48	1.1453	Communications
Electric, Gas, and Sanitary Services	49	1.1104	Utilities
Wholesale Trade - Durable Goods	50	1.1260	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1260	Wholesale trade
Building Materials & Garden Supplies	52	1.1062	Retail trade
General Merchandise Stores	53	1.1062	Retail trade
Food Stores	54	1.1062	Retail trade
Automotive Dealers & Service Stations	55	1.1062	Retail trade
Apparel and Accessory Stores	56	1.1062	Retail trade
Furniture and Homefurnishing Stores	57	1.1062	Retail trade
Eating and Drinking Places	58	1.1062	Retail trade
Misc. Retail	59	1.1062	Retail trade
Depository Institutions	60	1.1307	Banks & investment
Nondepository Institutions	61	1.1307	Banks & investment
Security and Commodity Brokers	62	1.1307	Banks & investment
Insurance Carriers	63	1.1121	Insurance

Description	SIC	MS	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1121	Insurance
Real Estate	65	1.1109	Real estate
Holding and Other Investment Offices	67	1.1307	Banks & investment
Hotels and Other Lodging Places	70	1.1008	Hotels & lodging
Personal Services	72	1.0521	Personal services
Business Services	73	1.1720	Business services
Auto Repair, Services, and Parking	75	1.0843	Auto repair & parking
Misc. Repair Services	76	1.1720	Business services
Motion Pictures	78	1.1692	Amusement
Amusement & Recreation Services	79	1.1692	Amusement
Health Services	80	1.1519	Health services
Legal Services	81	1.0870	Legal services
Educational Services	82	1.0926	Educational services
Social Services	83	1.1317	Social services
Museums, Botanical, Zoological Gardens	84	1.1492	Other services
Membership Organizations	86	1.1317	Social services
Engineering & Management Services	87	1.1492	Other services
Private Households	88	1.0181	Private households
Services, NEC	89	1.1492	Other services
Executive, Legislative, and General	91	1.0485	Government
Justice, Public Order, and Safety	92	1.0638	State and local
Finance, Taxation, & Monetary Policy	93	1.0638	State and local
Administration of Human Resources	94	1.0638	State and local
Environmental Quality and Housing	95	1.0638	State and local
Administration of Economic Programs	96	1.0638	State and local
National Security and International Affairs	97	1.0485	Government

Source: Developed from BEA, 1995.

Table B-17
BEA Gross State Product (GSP) Growth factors by 2-Digit SIC for 2001 to 2007 for State of TN

Description	SIC	TN	BEA Surrogate
Agricultural Production - Crops	01	1.1257	Farm
Agricultural Production - Livestock	02	1.1257	Farm
Agricultural Services	07	1.2508	Agricultural services
Forestry	08	1.2508	Agricultural services
Fishing, Hunting, and Trapping	09	1.2508	Agricultural services
Metal Mining	10	1.1861	Metal mining
Coal mining	11	1.0388	Coal mining
Coal Mining	12	1.0388	Coal mining
Oil and Gas Extraction	13	0.9987	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0715	Nonmetallic minerals
General Building Contractors	15	1.0682	Construction
Heavy Construction	16	1.0682	Construction
Special Trade Contractors	17	1.0682	Construction
Food and Kindred Products	20	1.0806	Food & kindred
Tobacco Products	21	0.8605	Tobacco products
Textile Mill Products	22	1.0538	Textile mill prod.
Apparel and Other Textile Products	23	1.1022	Apparel & textile
Lumber and Wood Products	24	1.0798	Lumber & wood
Furniture and Fixtures	25	1.1131	Furniture
Paper and Allied Products	26	1.1408	Paper products
Printing and Publishing	27	1.0504	Printing & publish.
Chemical and Allied Products	28	1.0805	Chemicals
Petroleum and Coal Products	29	1.0844	Petroleum products
Rubber and Misc. Plastic Products	30	1.1812	Rubber & plastics
Leather and Leather Products	31	0.9722	Leather products
Stone, Clay and Glass Products	32	1.0697	Stone, clay, glass
Primary Metal Industries	33	1.0520	Primary metals

Description	SIC	TN	BEA Surrogate
Fabricated Metal Industries	34	1.0663	Fabricated metals
Industrial Machinery and Equipment	35	1.1875	Indust. machinery
Electronic and Other Electronic Equipment	36	1.1369	Electronic equip.
Transportation Equipment	37	1.1698	Other trans. equip.
Instruments and Related Products	38	1.1255	Instruments
Misc. Manufacturing Industries	39	1.1284	Misc. manufacturing
Railroad Transportation	40	1.1587	Railroad transport.
Local and Interurban Passenger Transit	41	1.0880	Local & interurban
Trucking and Warehousing	42	1.1312	Trucking
Water Transportation	44	1.0609	Water transportation
Transportation by Air	45	1.2300	Transportation by air
Pipelines except Natural Gas	46	1.0077	Pipelines
Transportation Services	47	1.1819	Transport. services
Communications	48	1.1679	Communications
Electric, Gas, and Sanitary Services	49	1.1389	Utilities
Wholesale Trade - Durable Goods	50	1.1406	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1406	Wholesale trade
Building Materials & Garden Supplies	52	1.1190	Retail trade
General Merchandise Stores	53	1.1190	Retail trade
Food Stores	54	1.1190	Retail trade
Automotive Dealers & Service Stations	55	1.1190	Retail trade
Apparel and Accessory Stores	56	1.1190	Retail trade
Furniture and Homefurnishing Stores	57	1.1190	Retail trade
Eating and Drinking Places	58	1.1190	Retail trade
Misc. Retail	59	1.1190	Retail trade
Depository Institutions	60	1.1582	Banks & investment
Nondepository Institutions	61	1.1582	Banks & investment
Security and Commodity Brokers	62	1.1582	Banks & investment
Insurance Carriers	63	1.1225	Insurance

Description	SIC	TN	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.1225	Insurance
Real Estate	65	1.1250	Real estate
Holding and Other Investment Offices	67	1.1582	Banks & investment
Hotels and Other Lodging Places	70	1.1374	Hotels & lodging
Personal Services	72	1.0603	Personal services
Business Services	73	1.1780	Business services
Auto Repair, Services, and Parking	75	1.1051	Auto repair & parking
Misc. Repair Services	76	1.1780	Business services
Motion Pictures	78	1.1705	Amusement
Amusement & Recreation Services	79	1.1705	Amusement
Health Services	80	1.1498	Health services
Legal Services	81	1.1018	Legal services
Educational Services	82	1.1201	Educational services
Social Services	83	1.1654	Social services
Museums, Botanical, Zoological Gardens	84	1.1900	Other services
Membership Organizations	86	1.1654	Social services
Engineering & Management Services	87	1.1900	Other services
Private Households	88	1.0368	Private households
Services, NEC	89	1.1900	Other services
Executive, Legislative, and General	91	1.0668	Government
Justice, Public Order, and Safety	92	1.0896	State and local
Finance, Taxation, & Monetary Policy	93	1.0896	State and local
Administration of Human Resources	94	1.0896	State and local
Environmental Quality and Housing	95	1.0896	State and local
Administration of Economic Programs	96	1.0896	State and local
National Security and International Affairs	97	1.0668	Government

Source: Developed from BEA, 1995.

Table B-18
BEA Gross State Product (GSP) Growth factors by 2-Digit SIC for 2002 to 2007 for State of TN

Description	SIC	TN	BEA Surrogate
Agricultural Production - Crops	01	1.1016	Farm
Agricultural Production - Livestock	02	1.1016	Farm
Agricultural Services	07	1.2005	Agricultural services
Forestry	08	1.2005	Agricultural services
Fishing, Hunting, and Trapping	09	1.2005	Agricultural services
Metal Mining	10	1.1501	Metal mining
Coal mining	11	1.0288	Coal mining
Coal Mining	12	1.0288	Coal mining
Oil and Gas Extraction	13	0.9993	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0596	Nonmetallic minerals
General Building Contractors	15	1.0561	Construction
Heavy Construction	16	1.0561	Construction
Special Trade Contractors	17	1.0561	Construction
Food and Kindred Products	20	1.0663	Food & kindred
Tobacco Products	21	0.8826	Tobacco products
Textile Mill Products	22	1.0443	Textile mill prod.
Apparel and Other Textile Products	23	1.0839	Apparel & textile
Lumber and Wood Products	24	1.0653	Lumber & wood
Furniture and Fixtures	25	1.0923	Furniture
Paper and Allied Products	26	1.1147	Paper products
Printing and Publishing	27	1.0416	Printing & publish.
Chemical and Allied Products	28	1.0662	Chemicals
Petroleum and Coal Products	29	1.0692	Petroleum products
Rubber and Misc. Plastic Products	30	1.1466	Rubber & plastics
Leather and Leather Products	31	0.9768	Leather products
Stone, Clay and Glass Products	32	1.0577	Stone, clay, glass
Primary Metal Industries	33	1.0429	Primary metals

Description	SIC	TN	BEA Surrogate
Fabricated Metal Industries	34	1.0545	Fabricated metals
Industrial Machinery and Equipment	35	1.1503	Indust. machinery
Electronic and Other Electronic Equipment	36	1.1108	Electronic equip.
Transportation Equipment	37	1.1372	Other trans. equip.
Instruments and Related Products	38	1.1025	Instruments
Misc. Manufacturing Industries	39	1.1047	Misc. manufacturing
Railroad Transportation	40	1.1279	Railroad transport.
Local and Interurban Passenger Transit	41	1.0720	Local & interurban
Trucking and Warehousing	42	1.1068	Trucking
Water Transportation	44	1.0500	Water transportation
Transportation by Air	45	1.1844	Transportation by air
Pipelines except Natural Gas	46	1.0069	Pipelines
Transportation Services	47	1.1466	Transport. services
Communications	48	1.1358	Communications
Electric, Gas, and Sanitary Services	49	1.1138	Utilities
Wholesale Trade - Durable Goods	50	1.1139	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.1139	Wholesale trade
Building Materials & Garden Supplies	52	1.0974	Retail trade
General Merchandise Stores	53	1.0974	Retail trade
Food Stores	54	1.0974	Retail trade
Automotive Dealers & Service Stations	55	1.0974	Retail trade
Apparel and Accessory Stores	56	1.0974	Retail trade
Furniture and Homefurnishing Stores	57	1.0974	Retail trade
Eating and Drinking Places	58	1.0974	Retail trade
Misc. Retail	59	1.0974	Retail trade
Depository Institutions	60	1.1282	Banks & investment
Nondepository Institutions	61	1.1282	Banks & investment
Security and Commodity Brokers	62	1.1282	Banks & investment
Insurance Carriers	63	1.0999	Insurance

Description	SIC	TN	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.0999	Insurance
Real Estate	65	1.1018	Real estate
Holding and Other Investment Offices	67	1.1282	Banks & investment
Hotels and Other Lodging Places	70	1.1117	Hotels & lodging
Personal Services	72	1.0498	Personal services
Business Services	73	1.1432	Business services
Auto Repair, Services, and Parking	75	1.0857	Auto repair & parking
Misc. Repair Services	76	1.1432	Business services
Motion Pictures	78	1.1379	Amusement
Amusement & Recreation Services	79	1.1379	Amusement
Health Services	80	1.1213	Health services
Legal Services	81	1.0824	Legal services
Educational Services	82	1.0981	Educational services
Social Services	83	1.1336	Social services
Museums, Botanical, Zoological Gardens	84	1.1531	Other services
Membership Organizations	86	1.1336	Social services
Engineering & Management Services	87	1.1531	Other services
Private Households	88	1.0306	Private households
Services, NEC	89	1.1531	Other services
Executive, Legislative, and General	91	1.0550	Government
Justice, Public Order, and Safety	92	1.0733	State and local
Finance, Taxation, & Monetary Policy	93	1.0733	State and local
Administration of Human Resources	94	1.0733	State and local
Environmental Quality and Housing	95	1.0733	State and local
Administration of Economic Programs	96	1.0733	State and local
National Security and International Affairs	97	1.0550	Government

Source: Developed from BEA, 1995.

Table B-19
BEA Employment Growth Factors by 2-Digit SIC for 1999 to 2007 for State of LA

Description	SIC	LA	BEA Surrogate
Agricultural Production - Crops	01	0.9463	Farm
Agricultural Production - Livestock	02	0.9463	Farm
Agricultural Services	07	1.1820	Agricultural services
Forestry	08	1.1820	Agricultural services
Fishing, Hunting, and Trapping	09	1.1820	Agricultural services
Metal Mining	10	1.2000	Metal mining
Coal mining	11	1.0000	Coal mining
Coal Mining	12	1.0000	Coal mining
Oil and Gas Extraction	13	0.9182	Oil & gas
Nonmetallic Minerals except Fuels	14	1.0000	Nonmetallic minerals
General Building Contractors	15	1.0738	Construction
Heavy Construction	16	1.0738	Construction
Special Trade Contractors	17	1.0738	Construction
Food and Kindred Products	20	1.0038	Food & kindred
Tobacco Products	21	1.0000	Tobacco products
Textile Mill Products	22	1.0866	Textile mill prod.
Apparel and Other Textile Products	23	1.0165	Apparel & textile
Lumber and Wood Products	24	1.0106	Lumber & wood
Furniture and Fixtures	25	1.0500	Furniture
Paper and Allied Products	26	0.9966	Paper products
Printing and Publishing	27	1.0557	Printing & publish.
Chemical and Allied Products	28	1.0322	Chemicals
Petroleum and Coal Products	29	0.9521	Petroleum products
Rubber and Misc. Plastic Products	30	1.2347	Rubber & plastics
Leather and Leather Products	31	1.0000	Leather products
Stone, Clay and Glass Products	32	0.9861	Stone, clay, glass
Primary Metal Industries	33	0.9511	Primary metals

Description	SIC	LA	BEA Surrogate
Fabricated Metal Industries	34	0.9890	Fabricated metals
Industrial Machinery and Equipment	35	0.9981	Indust. machinery
Electronic and Other Electronic Equipment	36	0.9084	Electronic equip.
Transportation Equipment	37	1.0334	Other trans. equip.
Instruments and Related Products	38	1.0909	Instruments
Misc. Manufacturing Industries	39	1.0165	Misc. manufacturing
Railroad Transportation	40	0.9935	Railroad transport.
Local and Interurban Passenger Transit	41	1.0932	Local & interurban
Trucking and Warehousing	42	1.0926	Trucking
Water Transportation	44	0.9740	Water transportation
Transportation by Air	45	1.0787	Transportation by air
Pipelines except Natural Gas	46	1.0000	Pipelines
Transportation Services	47	1.1702	Transport. services
Communications	48	0.9781	Communications
Electric, Gas, and Sanitary Services	49	1.0504	Utilities
Wholesale Trade - Durable Goods	50	1.0736	Wholesale trade
Wholesale Trade - Nondurable Goods	51	1.0736	Wholesale trade
Building Materials & Garden Supplies	52	1.0796	Retail trade
General Merchandise Stores	53	1.0796	Retail trade
Food Stores	54	1.0796	Retail trade
Automotive Dealers & Service Stations	55	1.0796	Retail trade
Apparel and Accessory Stores	56	1.0796	Retail trade
Furniture and Homefurnishing Stores	57	1.0796	Retail trade
Eating and Drinking Places	58	1.0796	Retail trade
Misc. Retail	59	1.0796	Retail trade
Depository Institutions	60	1.0639	Banks & investment
Nondepository Institutions	61	1.0639	Banks & investment
Security and Commodity Brokers	62	1.0639	Banks & investment
Insurance Carriers	63	1.0948	Insurance

Description	SIC	LA	BEA Surrogate
Insurance Agents, Brokers & Service	64	1.0948	Insurance
Real Estate	65	1.0983	Real estate
Holding and Other Investment Offices	67	1.0639	Banks & investment
Hotels and Other Lodging Places	70	1.1209	Hotels & lodging
Personal Services	72	1.0588	Personal services
Business Services	73	1.1965	Business services
Auto Repair, Services, and Parking	75	1.1311	Auto repair & parking
Misc. Repair Services	76	1.1965	Business services
Motion Pictures	78	1.1349	Amusement
Amusement & Recreation Services	79	1.1349	Amusement
Health Services	80	1.1980	Health services
Legal Services	81	1.1147	Legal services
Educational Services	82	1.1083	Educational services
Social Services	83	1.1620	Social services
Museums, Botanical, Zoological Gardens	84	1.1641	Other services
Membership Organizations	86	1.1620	Social services
Engineering & Management Services	87	1.1641	Other services
Private Households	88	0.8882	Private households
Services, NEC	89	1.1641	Other services
Executive, Legislative, and General	91	1.0493	Government
Justice, Public Order, and Safety	92	1.0667	State and local
Finance, Taxation, & Monetary Policy	93	1.0667	State and local
Administration of Human Resources	94	1.0667	State and local
Environmental Quality and Housing	95	1.0667	State and local
Administration of Economic Programs	96	1.0667	State and local
National Security and International Affairs	97	1.0493	Government

Source: Developed from BEA, 1995.

Table B-20
Energy Adjustment Factors applied to the Point Combustion Sources

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Steam Coal	10200101	0.8780
Industrial	Total Industrial	Steam Coal	10200104	0.8780
Industrial	Total Industrial	Steam Coal	10200107	0.8780
Industrial	Total Industrial	Steam Coal	10200117	0.8780
Industrial	Total Industrial	Steam Coal	10200201	0.8780
Industrial	Total Industrial	Steam Coal	10200202	0.8780
Industrial	Total Industrial	Steam Coal	10200203	0.8780
Industrial	Total Industrial	Steam Coal	10200204	0.8780
Industrial	Total Industrial	Steam Coal	10200205	0.8780
Industrial	Total Industrial	Steam Coal	10200206	0.8780
Industrial	Total Industrial	Steam Coal	10200210	0.8780
Industrial	Total Industrial	Steam Coal	10200212	0.8780
Industrial	Total Industrial	Steam Coal	10200213	0.8780
Industrial	Total Industrial	Steam Coal	10200217	0.8780
Industrial	Total Industrial	Steam Coal	10200218	0.8780
Industrial	Total Industrial	Steam Coal	10200219	0.8780
Industrial	Total Industrial	Steam Coal	10200221	0.8780
Industrial	Total Industrial	Steam Coal	10200222	0.8780
Industrial	Total Industrial	Steam Coal	10200223	0.8780
Industrial	Total Industrial	Steam Coal	10200224	0.8780
Industrial	Total Industrial	Steam Coal	10200225	0.8780
Industrial	Total Industrial	Steam Coal	10200226	0.8780
Industrial	Total Industrial	Steam Coal	10200229	0.8780
Industrial	Total Industrial	Steam Coal	10200300	0.8780
Industrial	Total Industrial	Steam Coal	10200301	0.8780
Industrial	Total Industrial	Steam Coal	10200302	0.8780
Industrial	Total Industrial	Steam Coal	10200303	0.8780

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Steam Coal	10200304	0.8780
Industrial	Total Industrial	Steam Coal	10200306	0.8780
Industrial	Total Industrial	Steam Coal	10200307	0.8780
Industrial	Total Industrial	Residual	10200401	0.9650
Industrial	Total Industrial	Residual	10200402	0.9650
Industrial	Total Industrial	Residual	10200403	0.9650
Industrial	Total Industrial	Residual	10200404	0.9650
Industrial	Total Industrial	Residual	10200405	0.9650
Industrial	Total Industrial	Distillate	10200501	0.9680
Industrial	Total Industrial	Distillate	10200502	0.9680
Industrial	Total Industrial	Distillate	10200503	0.9680
Industrial	Total Industrial	Distillate	10200504	0.9680
Industrial	Total Industrial	Distillate	10200505	0.9680
Industrial	Total Industrial	Natural Gas	10200601	0.9130
Industrial	Total Industrial	Natural Gas	10200602	0.9130
Industrial	Total Industrial	Natural Gas	10200603	0.9130
Industrial	Total Industrial	Natural Gas	10200604	0.9130
Industrial	Refining	Still Gas	10200701	1.1740
Industrial	Iron and Steel	Blast Furnace and Coke Oven Gas	10200704	0.8790
Industrial	Iron and Steel	Blast Furnace and Coke Oven Gas	10200707	0.8790
Industrial	Total Industrial	Total Delivered Energy	10200710	0.9230
Industrial	Total Industrial	Total Delivered Energy	10200799	0.9230
Industrial	Total Industrial	Steam Coal	10200802	0.8780
Industrial	Total Industrial	Steam Coal	10200804	0.8780
Industrial	Total Industrial	Renewables	10200901	0.9570
Industrial	Total Industrial	Renewables	10200902	0.9570
Industrial	Total Industrial	Renewables	10200903	0.9570
Industrial	Total Industrial	Renewables	10200904	0.9570
Industrial	Total Industrial	Renewables	10200905	0.9570

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Renewables	10200906	0.9570
Industrial	Total Industrial	Renewables	10200907	0.9570
Industrial	Total Industrial	Renewables	10200910	0.9570
Industrial	Total Industrial	Renewables	10200911	0.9570
Industrial	Total Industrial	Renewables	10200912	0.9570
Industrial	Total Industrial	LPG	10201001	0.9300
Industrial	Total Industrial	LPG	10201002	0.9300
Industrial	Total Industrial	LPG	10201003	0.9300
Industrial	Total Industrial	Renewables	10201101	0.9570
Industrial	Total Industrial	Renewables	10201201	0.9570
Industrial	Total Industrial	Renewables	10201202	0.9570
Industrial	Total Industrial	Renewables	10201301	0.9570
Industrial	Total Industrial	Other Petroleum	10201302	0.9600
Industrial	Total Industrial	Natural Gas	10201401	0.9130
Industrial	Total Industrial	Total Delivered Energy	10201402	0.9230
Industrial	Total Industrial	Distillate	10201403	0.9680
Industrial	Total Industrial	Residual	10201404	0.9650
Industrial	Total Industrial	Motor Gasoline	10201601	1.0030
Industrial	Total Industrial	Motor Gasoline	10201701	1.0030
Commercial		Coal	10300101	0.9940
Commercial		Coal	10300102	0.9940
Commercial		Coal	10300103	0.9940
Commercial		Coal	10300203	0.9940
Commercial		Coal	10300205	0.9940
Commercial		Coal	10300206	0.9940
Commercial		Coal	10300207	0.9940
Commercial		Coal	10300208	0.9940
Commercial		Coal	10300209	0.9940
Commercial		Coal	10300211	0.9940

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Commercial		Coal	10300214	0.9940
Commercial		Coal	10300216	0.9940
Commercial		Coal	10300217	0.9940
Commercial		Coal	10300218	0.9940
Commercial		Coal	10300221	0.9940
Commercial		Coal	10300222	0.9940
Commercial		Coal	10300223	0.9940
Commercial		Coal	10300224	0.9940
Commercial		Coal	10300225	0.9940
Commercial		Coal	10300226	0.9940
Commercial		Coal	10300300	0.9940
Commercial		Coal	10300305	0.9940
Commercial		Coal	10300306	0.9940
Commercial		Coal	10300307	0.9940
Commercial		Coal	10300309	0.9940
Commercial		Residual	10300401	0.9730
Commercial		Residual	10300402	0.9730
Commercial		Residual	10300403	0.9730
Commercial		Residual	10300404	0.9730
Commercial		Distillate	10300501	0.8550
Commercial		Distillate	10300502	0.8550
Commercial		Distillate	10300503	0.8550
Commercial		Distillate	10300504	0.8550
Commercial		Natural Gas	10300601	0.9740
Commercial		Natural Gas	10300602	0.9740
Commercial		Natural Gas	10300603	0.9740
Commercial		Renewables	10300701	1.0390
Commercial		Total Delivered Energy	10300799	0.9970
Commercial		Renewables	10300811	1.0390

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Commercial		Renewables	10300901	1.0390
Commercial		Renewables	10300902	1.0390
Commercial		Renewables	10300903	1.0390
Commercial		Renewables	10300910	1.0390
Commercial		Renewables	10300911	1.0390
Commercial		Renewables	10300912	1.0390
Commercial		LPG	10301001	0.9920
Commercial		LPG	10301002	0.9920
Commercial		LPG	10301003	0.9920
Commercial		Renewables	10301201	1.0390
Commercial		Renewables	10301202	1.0390
Commercial		Renewables	10301301	1.0390
Commercial		Total Petroleum	10301302	0.8960
Commercial		Renewables	10301303	1.0390
Industrial	Total Industrial	Steam Coal	10500102	0.8780
Industrial	Total Industrial	Distillate	10500105	0.9680
Industrial	Total Industrial	Natural Gas	10500106	0.9130
Industrial	Total Industrial	LPG	10500110	0.9300
Industrial	Total Industrial	Other Petroleum	10500113	0.9600
Industrial	Total Industrial	Other Petroleum	10500114	0.9600
Commercial		Coal	10500202	0.9940
Commercial		Distillate	10500205	0.8550
Commercial		Natural Gas	10500206	0.9740
Commercial		Renewables	10500209	1.0390
Commercial		LPG	10500210	0.9920
Commercial		Total Petroleum	10500213	0.8960
Commercial		Total Petroleum	10500214	0.8960
Industrial	Total Industrial	Distillate	20200101	0.9680
Industrial	Total Industrial	Distillate	20200102	0.9680

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Distillate	20200103	0.9680
Industrial	Total Industrial	Distillate	20200104	0.9680
Industrial	Total Industrial	Distillate	20200105	0.9680
Industrial	Total Industrial	Distillate	20200106	0.9680
Industrial	Total Industrial	Distillate	20200107	0.9680
Industrial	Total Industrial	Distillate	20200108	0.9680
Industrial	Total Industrial	Distillate	20200109	0.9680
Industrial	Total Industrial	Natural Gas	20200201	0.9130
Industrial	Total Industrial	Natural Gas	20200202	0.9130
Industrial	Total Industrial	Natural Gas	20200203	0.9130
Industrial	Total Industrial	Natural Gas	20200204	0.9130
Industrial	Total Industrial	Natural Gas	20200205	0.9130
Industrial	Total Industrial	Natural Gas	20200206	0.9130
Industrial	Total Industrial	Natural Gas	20200207	0.9130
Industrial	Total Industrial	Natural Gas	20200208	0.9130
Industrial	Total Industrial	Natural Gas	20200209	0.9130
Industrial	Total Industrial	Natural Gas	20200252	0.9130
Industrial	Total Industrial	Natural Gas	20200253	0.9130
Industrial	Total Industrial	Natural Gas	20200254	0.9130
Industrial	Total Industrial	Natural Gas	20200255	0.9130
Industrial	Total Industrial	Natural Gas	20200256	0.9130
Industrial	Total Industrial	Motor Gasoline	20200301	1.0030
Industrial	Total Industrial	Motor Gasoline	20200305	1.0030
Industrial	Total Industrial	Motor Gasoline	20200306	1.0030
Industrial	Total Industrial	Motor Gasoline	20200307	1.0030
Industrial	Total Industrial	Distillate	20200401	0.9680
Industrial	Total Industrial	Total Petroleum	20200402	0.9380
Industrial	Total Industrial	Total Petroleum	20200403	0.9380
Industrial	Total Industrial	Total Delivered Energy	20200405	0.9230

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Total Delivered Energy	20200406	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200407	0.9230
Industrial	Total Industrial	Residual	20200501	0.9650
Industrial	Total Industrial	Residual	20200505	0.9650
Industrial	Total Industrial	Residual	20200506	0.9650
Industrial	Total Industrial	Residual	20200507	0.9650
Industrial	Total Industrial	Total Delivered Energy	20200701	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200702	0.9230
Industrial	Refining	Still Gas	20200705	1.1740
Industrial	Refining	Still Gas	20200706	1.1740
Industrial	Total Industrial	Total Delivered Energy	20200710	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200711	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200712	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200713	0.9230
Industrial	Total Industrial	Total Delivered Energy	20200714	0.9230
Industrial	Total Industrial	Other Petroleum	20200901	0.9600
Industrial	Total Industrial	Other Petroleum	20200902	0.9600
Industrial	Total Industrial	Other Petroleum	20200905	0.9600
Industrial	Total Industrial	Other Petroleum	20200906	0.9600
Industrial	Total Industrial	Other Petroleum	20200907	0.9600
Industrial	Total Industrial	Other Petroleum	20200908	0.9600
Industrial	Total Industrial	Other Petroleum	20200909	0.9600
Industrial	Total Industrial	LPG	20201001	0.9300
Industrial	Total Industrial	LPG	20201002	0.9300
Industrial	Total Industrial	LPG	20201005	0.9300
Industrial	Total Industrial	LPG	20201006	0.9300
Industrial	Total Industrial	LPG	20201007	0.9300
Industrial	Total Industrial	LPG	20201008	0.9300
Industrial	Total Industrial	LPG	20201009	0.9300

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	LPG	20201011	0.9300
Industrial	Total Industrial	LPG	20201012	0.9300
Industrial	Total Industrial	LPG	20201013	0.9300
Industrial	Total Industrial	LPG	20201014	0.9300
Industrial	Total Industrial	Motor Gasoline	20201601	1.0030
Industrial	Total Industrial	Motor Gasoline	20201602	1.0030
Industrial	Total Industrial	Motor Gasoline	20201605	1.0030
Industrial	Total Industrial	Motor Gasoline	20201606	1.0030
Industrial	Total Industrial	Motor Gasoline	20201607	1.0030
Industrial	Total Industrial	Motor Gasoline	20201608	1.0030
Industrial	Total Industrial	Motor Gasoline	20201609	1.0030
Industrial	Total Industrial	Motor Gasoline	20201701	1.0030
Industrial	Total Industrial	Motor Gasoline	20201702	1.0030
Industrial	Total Industrial	Motor Gasoline	20201705	1.0030
Industrial	Total Industrial	Motor Gasoline	20201706	1.0030
Industrial	Total Industrial	Motor Gasoline	20201707	1.0030
Industrial	Total Industrial	Motor Gasoline	20201708	1.0030
Industrial	Total Industrial	Motor Gasoline	20201709	1.0030
Industrial	Total Industrial	Total Delivered Energy	20280001	0.9230
Industrial	Total Industrial	Total Delivered Energy	20282001	0.9230
Industrial	Total Industrial	Total Delivered Energy	20282002	0.9230
Industrial	Total Industrial	Total Delivered Energy	20282599	0.9230
Commercial		Distillate	20300101	0.8550
Commercial		Distillate	20300102	0.8550
Commercial		Distillate	20300105	0.8550
Commercial		Distillate	20300106	0.8550
Commercial		Distillate	20300107	0.8550
Commercial		Distillate	20300108	0.8550
Commercial		Distillate	20300109	0.8550

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Commercial		Natural Gas	20300201	0.9740
Commercial		Natural Gas	20300202	0.9740
Commercial		Natural Gas	20300203	0.9740
Commercial		Natural Gas	20300204	0.9740
Commercial		Natural Gas	20300205	0.9740
Commercial		Natural Gas	20300206	0.9740
Commercial		Natural Gas	20300207	0.9740
Commercial		Natural Gas	20300208	0.9740
Commercial		Natural Gas	20300209	0.9740
Commercial		Motor Gasoline	20300301	0.8830
Commercial		Motor Gasoline	20300305	0.8830
Commercial		Motor Gasoline	20300306	0.8830
Commercial		Motor Gasoline	20300307	0.8830
Commercial		Renewables	20300701	1.0390
Commercial		Renewables	20300702	1.0390
Commercial		Renewables	20300705	1.0390
Commercial		Renewables	20300706	1.0390
Commercial		Renewables	20300707	1.0390
Commercial		Renewables	20300708	1.0390
Commercial		Renewables	20300709	1.0390
Commercial		Renewables	20300801	1.0390
Commercial		Renewables	20300802	1.0390
Commercial		Renewables	20300805	1.0390
Commercial		Renewables	20300806	1.0390
Commercial		Renewables	20300807	1.0390
Commercial		Renewables	20300808	1.0390
Commercial		Renewables	20300809	1.0390
Commercial		Kerosene	20300901	0.9820
Commercial		Kerosene	20300908	0.9820

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Commercial		Kerosene	20300909	0.9820
Commercial		LPG	20301001	0.9920
Commercial		LPG	20301002	0.9920
Commercial		LPG	20301005	0.9920
Commercial		LPG	20301006	0.9920
Commercial		LPG	20301007	0.9920
Commercial		Total Delivered Energy	20380001	0.9970
Commercial		Total Delivered Energy	20382001	0.9970
Commercial		Total Delivered Energy	20382002	0.9970
Commercial		Total Delivered Energy	20382599	0.9970
Industrial	Bulk Chemicals	Heat and Power-Distillate	30190001	0.8520
Industrial	Bulk Chemicals	Heat and Power-Residual	30190002	0.9630
Industrial	Bulk Chemicals	Heat and Power-Natural Gas	30190003	0.8870
Industrial	Bulk Chemicals	Heat and Power-Total	30190004	0.9140
Industrial	Bulk Chemicals	Heat and Power-Distillate	30190011	0.8520
Industrial	Bulk Chemicals	Heat and Power-Residual	30190012	0.9630
Industrial	Bulk Chemicals	Heat and Power-Natural Gas	30190013	0.8870
Industrial	Bulk Chemicals	Heat and Power-Total	30190014	0.9140
Industrial	Bulk Chemicals	Heat and Power-Distillate	30190021	0.8520
Industrial	Bulk Chemicals	Heat and Power-Residual	30190022	0.9630
Industrial	Bulk Chemicals	Heat and Power-Natural Gas	30190023	0.8870
Industrial	Bulk Chemicals	Heat and Power-Total	30190099	0.9140
Industrial	Food	Distillate	30290001	0.9320
Industrial	Food	Residual	30290002	0.9860
Industrial	Food	Natural Gas	30290003	0.8830
Industrial	Iron and Steel	Other Petroleum	30390001	0.9320
Industrial	Iron and Steel	Residual	30390002	0.8300
Industrial	Iron and Steel	Natural Gas	30390003	0.8840
Industrial	Iron and Steel	Total	30390004	0.8870

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Iron and Steel	Other Petroleum	30390011	0.9320
Industrial	Iron and Steel	Residual	30390012	0.8300
Industrial	Iron and Steel	Natural Gas	30390013	0.8840
Industrial	Iron and Steel	Total	30390014	0.8870
Industrial	Iron and Steel	Other Petroleum	30390021	0.9320
Industrial	Iron and Steel	Residual	30390022	0.8300
Industrial	Iron and Steel	Natural Gas	30390023	0.8840
Industrial	Iron and Steel	Total	30390024	0.8870
Industrial	Other Manufacturing	Distillate	30400406	1.0140
Industrial	Other Manufacturing	Natural Gas	30400407	0.9450
Industrial	Other Manufacturing	Distillate	30490001	1.0140
Industrial	Other Manufacturing	Residual	30490002	1.0310
Industrial	Other Manufacturing	Natural Gas	30490003	0.9450
Industrial	Other Manufacturing	Total	30490004	0.9650
Industrial	Other Manufacturing	Distillate	30490011	1.0140
Industrial	Other Manufacturing	Residual	30490012	1.0310
Industrial	Other Manufacturing	Natural Gas	30490013	0.9450
Industrial	Other Manufacturing	Total	30490014	0.9650
Industrial	Other Manufacturing	Distillate	30490021	1.0140
Industrial	Other Manufacturing	Residual	30490022	1.0310
Industrial	Other Manufacturing	Natural Gas	30490023	0.9450
Industrial	Other Manufacturing	Total	30490024	0.9650
Industrial	Other Manufacturing	Distillate	30490031	1.0140
Industrial	Other Manufacturing	Residual	30490032	1.0310
Industrial	Other Manufacturing	Natural Gas	30490033	0.9450
Industrial	Other Manufacturing	Total	30490034	0.9650
Industrial	Other Manufacturing	LPG	30490035	0.9030
Industrial	Refining	Natural Gas	30500206	1.2980
Industrial	Refining	Residual	30500207	1.0540

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Refining	Distillate	30500208	0.0000
Industrial	Refining	LPG	30500209	0.3150
Industrial	Refining	Other Petroleum	30500210	0.0000
Industrial	Refining	Natural Gas	30505020	1.2980
Industrial	Refining	Residual	30505021	1.0540
Industrial	Refining	Distillate	30505022	0.0000
Industrial	Refining	LPG	30505023	0.3150
Industrial	Mining	Distillate	30590001	1.0390
Industrial	Mining	Residual	30590002	1.1100
Industrial	Mining	Natural Gas	30590003	0.9350
Industrial	Mining	Other Petroleum	30590005	1.0730
Industrial	Mining	Distillate	30590011	1.0390
Industrial	Mining	Residual	30590012	1.1100
Industrial	Mining	Natural Gas	30590013	0.9350
Industrial	Mining	Total	30590022	1.0680
Industrial	Mining	Natural Gas	30590023	0.9350
Industrial	Refining	Total Petroleum	30600101	1.0600
Industrial	Refining	Natural Gas	30600102	1.2980
Industrial	Refining	Total Petroleum	30600103	1.0600
Industrial	Refining	Natural Gas	30600104	1.2980
Industrial	Refining	Natural Gas	30600105	1.2980
Industrial	Refining	Still Gas	30600106	1.1740
Industrial	Refining	LPG	30600107	0.3150
Industrial	Refining	Total	30600108	1.1400
Industrial	Refining	Residual	30600111	1.0540
Industrial	Refining	Total	30600199	1.1400
Industrial	Refining	Total	30600901	1.1400
Industrial	Refining	Total	30600902	1.1400
Industrial	Refining	Natural Gas	30600903	1.2980

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Refining	Still Gas	30600904	1.1740
Industrial	Refining	LPG	30600905	0.3150
Industrial	Refining	Total	30600999	1.1400
Industrial	Refining	Distillate	30609901	0.0000
Industrial	Refining	Residual	30609902	1.0540
Industrial	Refining	Natural Gas	30609903	1.2980
Industrial	Refining	Total	30609904	1.1400
Industrial	Refining	LPG	30609905	0.3150
Industrial	Paper	Distillate	30790001	0.8720
Industrial	Paper	Residual	30790002	0.8680
Industrial	Paper	Natural Gas	30790003	0.8130
Industrial	Paper	Distillate	30790011	0.8720
Industrial	Paper	Residual	30790012	0.8680
Industrial	Paper	Natural Gas	30790013	0.8130
Industrial	Paper	Total	30790014	0.9430
Industrial	Paper	Distillate	30790021	0.8720
Industrial	Paper	Residual	30790022	0.8680
Industrial	Paper	Natural Gas	30790023	0.8130
Industrial	Paper	Total	30790024	0.9430
Industrial	Other Manufacturing	Distillate	30890001	1.0140
Industrial	Other Manufacturing	Residual	30890002	1.0310
Industrial	Other Manufacturing	Natural Gas	30890003	0.9450
Industrial	Other Manufacturing	LPG	30890004	0.9030
Industrial	Other Manufacturing	Distillate	30890011	1.0140
Industrial	Other Manufacturing	Residual	30890012	1.0310
Industrial	Other Manufacturing	Natural Gas	30890013	0.9450
Industrial	Other Manufacturing	Natural Gas	30890023	0.9450
Industrial	Metals-Based Durables	Distillate	30990001	0.9110
Industrial	Metals-Based Durables	Residual	30990002	1.0160

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Metals-Based Durables	Natural Gas	30990003	0.8980
Industrial	Metals-Based Durables	Distillate	30990011	0.9110
Industrial	Metals-Based Durables	Residual	30990012	1.0160
Industrial	Metals-Based Durables	Natural Gas	30990013	0.8980
Industrial	Metals-Based Durables	Natural Gas	30990023	0.8980
Industrial	Mining	Distillate	31000401	1.0390
Industrial	Mining	Residual	31000402	1.1100
Industrial	Mining	Other Petroleum	31000403	1.0730
Industrial	Mining	Natural Gas	31000404	0.9350
Industrial	Mining	Total	31000405	1.0680
Industrial	Mining	Other Petroleum	31000406	1.0730
Industrial	Mining	Distillate	31000411	1.0390
Industrial	Mining	Residual	31000412	1.1100
Industrial	Mining	Other Petroleum	31000413	1.0730
Industrial	Mining	Natural Gas	31000414	0.9350
Industrial	Mining	Total	31000415	1.0680
Industrial	Metals-Based Durables	Distillate	31390001	0.9110
Industrial	Metals-Based Durables	Residual	31390002	1.0160
Industrial	Metals-Based Durables	Natural Gas	31390003	0.8980
Industrial	Total Industrial	Total Coal	39000189	0.8580
Industrial	Total Industrial	Total Coal	39000199	0.8580
Industrial	Cement	Steam Coal	39000201	0.8640
Industrial	Other Manufacturing	Steam Coal	39000203	1.0000
Industrial	Total Industrial	Total Coal	39000288	0.8580
Industrial	Total Industrial	Total Coal	39000289	0.8580
Industrial	Total Industrial	Total Coal	39000299	0.8580
Industrial	Total Industrial	Total Coal	39000389	0.8580
Industrial	Total Industrial	Total Coal	39000399	0.8580
Industrial	Cement	Residual	39000402	0.7250

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Other Manufacturing	Residual	39000403	1.0310
Industrial	Total Industrial	Residual	39000489	0.9650
Industrial	Total Industrial	Residual	39000499	0.9650
Industrial	Refining	Distillate	39000501	0.0000
Industrial	Cement	Distillate	39000502	0.6810
Industrial	Other Manufacturing	Distillate	39000503	1.0140
Industrial	Total Industrial	Distillate	39000589	0.9680
Industrial	Total Industrial	Distillate	39000598	0.9680
Industrial	Total Industrial	Distillate	39000599	0.9680
Industrial	Cement	Natural Gas	39000602	0.7360
Industrial	Other Manufacturing	Natural Gas	39000603	0.9450
Industrial	Iron and Steel	Natural Gas	39000605	0.8840
Industrial	Total Industrial	Natural Gas	39000689	0.9130
Industrial	Total Industrial	Natural Gas	39000699	0.9130
Industrial	Iron and Steel	Blast Furnace and Coke Oven Gas	39000701	0.8790
Industrial	Iron and Steel	Blast Furnace and Coke Oven Gas	39000702	0.8790
Industrial	Total Industrial	Total Delivered Energy	39000788	0.9230
Industrial	Iron and Steel	Blast Furnace and Coke Oven Gas	39000789	0.8790
Industrial	Total Industrial	Total Delivered Energy	39000797	0.9230
Industrial	Total Industrial	Total Delivered Energy	39000798	0.9230
Industrial	Total Industrial	Total Delivered Energy	39000799	0.9230
Industrial	Total Industrial	Metallurgical Coal	39000801	0.7160
Industrial	Total Industrial	Renewables	39000889	0.9570
Industrial	Total Industrial	Metallurgical Coal	39000899	0.7160
Industrial	Total Industrial	LPG	39000989	0.9300
Industrial	Total Industrial	Renewables	39000999	0.9570
Industrial	Total Industrial	LPG	39001089	0.9300
Industrial	Total Industrial	LPG	39001099	0.9300
Industrial	Total Industrial	Renewables	39001289	0.9570

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Renewables	39001299	0.9570
Industrial	Total Industrial	Total Petroleum	39001385	0.9380
Industrial	Total Industrial	Renewables	39001389	0.9570
Industrial	Total Industrial	Renewables	39001399	0.9570
Industrial	Total Industrial	Residual	39090001	0.9650
Industrial	Total Industrial	Residual	39090002	0.9650
Industrial	Total Industrial	Distillate	39090003	0.9680
Industrial	Total Industrial	Distillate	39090004	0.9680
Industrial	Total Industrial	Residual	39090005	0.9650
Industrial	Total Industrial	Residual	39090006	0.9650
Industrial	Total Industrial	Motor Gasoline	39090007	1.0030
Industrial	Total Industrial	Motor Gasoline	39090008	1.0030
Industrial	Total Industrial	Residual	39090009	0.9650
Industrial	Total Industrial	Residual	39090010	0.9650
Industrial	Total Industrial	Total Petroleum	39090011	0.9380
Industrial	Total Industrial	Total Petroleum	39090012	0.9380
Industrial	Total Industrial	Residual	39091001	0.9650
Industrial	Total Industrial	Residual	39091002	0.9650
Industrial	Total Industrial	Distillate	39091003	0.9680
Industrial	Total Industrial	Distillate	39091004	0.9680
Industrial	Total Industrial	Residual	39091005	0.9650
Industrial	Total Industrial	Residual	39091006	0.9650
Industrial	Total Industrial	Motor Gasoline	39091007	1.0030
Industrial	Total Industrial	Motor Gasoline	39091008	1.0030
Industrial	Total Industrial	Residual	39091009	0.9650
Industrial	Total Industrial	Residual	39091010	0.9650
Industrial	Total Industrial	Total Petroleum	39091011	0.9380
Industrial	Total Industrial	Total Petroleum	39091012	0.9380
Industrial	Total Industrial	Natural Gas	39092050	0.9130

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	LPG	39092051	0.9300
Industrial	Total Industrial	Renewables	39092052	0.9570
Industrial	Refining	Still Gas	39092053	1.1740
Industrial	Total Industrial	Renewables	39092054	0.9570
Industrial	Total Industrial	Total Delivered Energy	39092055	0.9230
Industrial	Total Industrial	Total Petroleum	39092056	0.9380
Industrial	Other Manufacturing	Distillate	39900501	1.0140
Industrial	Other Manufacturing	Natural Gas	39900601	0.9450
Industrial	Other Manufacturing	Total	39900701	0.9650
Industrial	Refining	Still Gas	39900711	1.1740
Industrial	Other Manufacturing	Renewables	39900721	1.0140
Industrial	Other Manufacturing	Renewables	39900801	1.0140
Industrial	Other Manufacturing	LPG	39901001	0.9030
Industrial	Other Manufacturing	Total Petroleum	39901601	0.9590
Industrial	Other Manufacturing	Total Petroleum	39901701	0.9590
Industrial	Other Manufacturing	Distillate	39990001	1.0140
Industrial	Other Manufacturing	Residual	39990002	1.0310
Industrial	Other Manufacturing	Natural Gas	39990003	0.9450
Industrial	Other Manufacturing	Total	39990004	0.9650
Industrial	Other Manufacturing	Distillate	39990011	1.0140
Industrial	Other Manufacturing	Residual	39990012	1.0310
Industrial	Other Manufacturing	Natural Gas	39990013	0.9450
Industrial	Other Manufacturing	Total	39990014	0.9650
Industrial	Other Manufacturing	Distillate	39990021	1.0140
Industrial	Other Manufacturing	Residual	39990022	1.0310
Industrial	Other Manufacturing	Natural Gas	39990023	0.9450
Industrial	Other Manufacturing	Total	39990024	0.9650
Industrial	Total Industrial	Natural Gas	40201001	0.9130
Industrial	Total Industrial	Distillate	40201002	0.9680

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Industrial	Total Industrial	Residual	40201003	0.9650
Industrial	Total Industrial	LPG	40201004	0.9300
Industrial	Total Industrial	Distillate	40290011	0.9680
Industrial	Total Industrial	Residual	40290012	0.9650
Industrial	Total Industrial	Natural Gas	40290013	0.9130
Industrial	Total Industrial	Natural Gas	40290023	0.9130
Industrial	Total Industrial	Distillate	49090011	0.9680
Industrial	Total Industrial	Residual	49090012	0.9650
Industrial	Total Industrial	Natural Gas	49090013	0.9130
Industrial	Total Industrial	Total Petroleum	49090015	0.9380
Industrial	Total Industrial	Distillate	49090021	0.9680
Industrial	Total Industrial	Residual	49090022	0.9650
Industrial	Total Industrial	Natural Gas	49090023	0.9130
Commercial		Renewables	50100103	1.0390
Commercial		Renewables	50100108	1.0390
Commercial		Renewables	50100420	1.0390
Commercial		Renewables	50100421	1.0390
Commercial		Renewables	50100422	1.0390
Commercial		Renewables	50100430	1.0390
Commercial		Renewables	50100431	1.0390
Commercial		Renewables	50100432	1.0390
Commercial		Renewables	50100433	1.0390
Commercial		Coal	50190002	0.9940
Commercial		Distillate	50190005	0.8550
Commercial		Natural Gas	50190006	0.9740
Commercial		LPG	50190010	0.9920
Commercial		Total Delivered Energy	50290002	0.9970
Commercial		Total Delivered Energy	50290005	0.9970
Commercial		Total Delivered Energy	50290006	0.9970

Sector	Industry Sector	Fuel	SCC	Adjustment Factor
Commercial		Total Delivered Energy	50290010	0.9970
Industrial	Total Industrial	Total Coal	50390002	0.8580
Industrial	Total Industrial	Distillate	50390005	0.9680
Industrial	Total Industrial	Natural Gas	50390006	0.9130
Industrial	Total Industrial	Total Delivered Energy	50390007	0.9230
Industrial	Total Industrial	LPG	50390010	0.9300

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-21
Point Source CAA Baseline VOC Control Assumptions

Source Category	Control Efficiency (%)
National Rules	
Marine vessel loading: petroleum liquids	80
Treatment, storage, and disposal facilities (TSDFs)	96
Municipal solid waste landfills	82

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-22
Point Source MACT Control Assumptions

Source Category	VOC Control Efficiency (%)*
Benzene National Emission Standards for Hazardous Air Pollutants (NESHAP) (national)	
By-product coke mfg	85
By-product coke - flushing-liquor circulation tank	95
By-product coke – excess-NH_3 liquor tank	98
By-product coke mfg. - tar storage	98
By-product coke mfg. - light oil sump	98
By-product coke mfg. - light oil dec/cond vents	98
By-product coke mfg. - tar bottom final cooler	81
By-product coke mfg. - naphthalene processing	100
By-product coke mfg. - equipment leaks	83
By-product coke manufacture – other	94
By-product coke manufacture - oven charging	94
Coke ovens - door and topside leaks	94
Coke oven by-product plants	94
2-Year MACT (national)	
Synthetic Organic Chemical Manufacturing Industry (SOCMI) Hazardous Organic NESHAP (HON)	
SOCMI processes	79
Volatile organic liquid storage	95
SOCMI fugitives (equipment leak detection and repair)	60
SOCMI wastewater	0
Ethylene oxide manufacture	98
Phenol manufacture	98
Acrylonitrile manufacture	98
Polypropylene manufacture	98
Polyethylene manufacture	98
Ethylene manufacture	98

Source Category	VOC Control Efficiency (%)*
Dry Cleaning	
Perchloroethylene	95
Other	70
4-Year MACT (national)	
TSDFs (offsite waste operations)	96
Shipbuilding and repair	24
Polymers and resins II	78
Polymers and resins IV	70
Styrene-butadiene rubber manufacture (polymers & resins group I)	70
Wood furniture surface coating	30
Aircraft surface coating (aerospace)	60
Petroleum Refineries: other sources	
Fixed roof petroleum product tanks	98
Fixed roof gasoline tanks	96
External floating roof petroleum product tanks	90
External floating roof gasoline tanks	95
Petroleum refinery wastewater treatment	72
Petroleum refinery fugitives	72
Petroleum refineries - Blowdown w/o control	78
Vacuum distillation	72
Halogenated Solvent Cleaners	
Open top degreasing – halogenated	63
In-line (conveyorized) degreasing – halogenated	39
Printing	
Flexographic	32
Gravure	27

Source Category	VOC Control Efficiency (%)*
Gasoline Marketing	
Storage	5
Splash loading	99
Balanced loading	87
Submerged loading	99
Transit	5
Leaks	39
7/10-Year MACT (national)	
Paint and varnish manufacture	35
Rubber tire manufacture	70
Green tire spray	90
Automobile surface coating	79
Beverage can surface coating	57
Paper surface coating	78
Flatwood surface coating	90
Fabric printing	80
Metal surface coating	90
Plastic parts surface coating	45
Pulp and paper production	70
Agricultural chemical production	79
Pharmaceutical production	79
Polyesters	70
Fabric coating	70
Petroleum refineries - fluid catalytic cracking	70
Oil and natural gas production	90
Explosives	70
Plywood/particle board	70
Reinforced plastics	70

Source Category	VOC Control Efficiency (%)*
Publicly-Owned Treatment Works (POTWs)	70
Phthalate plasticizers	70
Polymers and resins III	78
Rayon production	70
Polyvinyl chloride	70
Spandex production	70
Nylon 6 production	70
Alkyd resins	70
Polyester resins	70
Chelating agents	70

NOTE: *From uncontrolled levels.

Source: EPA "Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-23
Non-VOC Related MACT Assumptions

Source Category	Pollutant	Percentage Reduction (%)*
Medical Waste Incineration	NOx	20

NOTE: *From uncontrolled levels.

Source: Provided by E. H. Pechan & Associates, Inc, February 2002.
The information were used to develop the base year and future year inventories for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking

Table B-24
NO_x Reduction Levels from Uncontrolled Emissions for Non-EGU Sources

Source Category	Budget Reduction Percentage
ICI Boilers* – Coal/Wall	60
ICI Boilers – Coal/FBC	60
ICI Boilers – Coal/Stoker	60
ICI Boilers – Coal/Cyclone	60
ICI Boilers – Residual Oil	60
ICI Boilers – Distillate Oil	60
ICI Boilers – Natural Gas	60
ICI Boilers – Process Gas	60
ICI Boilers – LPG	60
ICI Boilers – Coke	60
Gas Turbines – Oil	60
Gas Turbines – Natural Gas	60
Gas Turbines – Jet Fuel	60
Internal Combustion Engines – Oil	90
Internal Combustion Engines – Gas	90
Internal Combustion Engines – Gas, Diesel, LPG	90
Cement Manufacturing – Dry	30
Cement Manufacturing – Wet	30
In-Process; Bituminous Coal; Cement Kiln	30

* Industrial/Commercial/Institutional Boilers

Source: EPA "Development of Emission Budget Inventories for Regional Transport NO_x SIP Call Technical Amendment Version"

Table B-25
Summary of 2007 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 1

NOX	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	1931	2118	2118	2118	2118	2118	1993	1931	1931	2118	2118	2118
Motor vehicle	5944	7147	7288	7218	7359	7854	6793	5944	5944	7288	7218	7359
Non-road	4880	6004	6004	6004	6004	6004	4880	4880	4880	6004	6004	6004
Low-level point	1697	1826	1826	1826	1826	1826	1740	1697	1697	1826	1826	1826
Biogenic	3411	3014	3040	3319	3475	3421	3406	3248	3239	3177	3016	2809
All low-level	17863	20110	20277	20485	20783	21225	18813	17700	17691	20414	20183	20117
Elevated point	7844	8407	8455	8435	8463	8441	8118	7844	7919	8476	8457	8463
Total Anthropogenic	22296	25503	25692	25602	25771	26244	23524	22296	22371	25713	25623	25771
TOTAL	**25707**	**28517**	**28731**	**28920**	**29246**	**29665**	**26930**	**25544**	**25609**	**28890**	**28640**	**28580**

VOC	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	11331	11335	11335	11335	11335	11335	11332	11331	11331	11335	11335	11335
Motor vehicle	3956	4756	4850	4803	4897	5227	4521	3956	3956	4850	4803	4897
Non-road	3259	2089	2089	2089	2089	2089	3259	3259	3259	2089	2089	2089
Low-level point	1460	2107	2107	2107	2107	2107	1586	1460	1460	2107	2107	2107
Biogenic	136177	93572	88106	97692	99489	96235	91448	84182	96556	92786	85907	72467
All low-level	156183	113859	108487	118026	119918	116993	112146	104187	116561	113168	106241	92895
Elevated point	459	521	522	522	522	521	482	459	461	522	522	522
Total Anthropogenic	20465	20808	20904	20857	20950	21280	21180	20465	20467	20904	20857	20950
TOTAL	**156642**	**114380**	**109009**	**118548**	**120440**	**117514**	**112628**	**104647**	**117023**	**113690**	**106763**	**93417**

CO	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	10351	10404	10404	10404	10404	10404	10369	10351	10351	10404	10404	10404
Motor vehicle	37153	44672	45556	45114	45999	49095	42460	37153	37153	45556	45114	45999
Non-road	34248	32828	32828	32828	32828	32828	34248	34248	34248	32828	32828	32828
Low-level point	3368	3674	3674	3674	3674	3674	3472	3368	3368	3674	3674	3674
All low-level	85120	91578	92462	92020	92904	96000	90549	85120	85120	92462	92020	92904
Elevated point	4671	5013	5020	5019	5015	5013	4893	4671	4685	5020	5019	5015
Total Anthropogenic	89790	96590	97482	97038	97919	101013	95441	89790	89805	97482	97038	97919
TOTAL	**89790**	**96590**	**97482**	**97038**	**97919**	**101013**	**95441**	**89790**	**89805**	**97482**	**97038**	**97919**

Table B-26
Summary of 2007 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 2

NOX	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	903	997	997	997	997	997	934	903	903	997	997	997
Motor vehicle	2543	3058	3119	3088	3149	3361	2907	2543	2543	3119	3088	3149
Non-road	1924	2344	2344	2344	2344	2344	1924	1924	1924	2344	2344	2344
Low-level point	619	667	667	667	667	667	634	619	619	667	667	667
Biogenic	1074	928	880	959	969	960	993	990	1002	952	900	858
All low-level	7062	7994	8006	8056	8126	8329	7392	6978	6990	8078	7996	8014
Elevated point	3220	3300	3346	3330	3339	3337	3237	3220	3266	3368	3351	3339
Total Anthropogenic	9208	10366	10472	10426	10495	10706	9636	9208	9254	10494	10447	10495
TOTAL	**10282**	**11294**	**11352**	**11385**	**11464**	**11666**	**10629**	**10198**	**10256**	**11446**	**11348**	**11353**

VOC	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	4815	4817	4817	4817	4817	4817	4816	4815	4815	4817	4817	4817
Motor vehicle	1691	2033	2073	2053	2093	2234	1932	1691	1691	2073	2053	2093
Non-road	1234	781	781	781	781	781	1234	1234	1234	781	781	781
Low-level point	642	992	992	992	992	992	710	642	642	992	992	992
Biogenic	84768	58404	52616	57869	57446	57926	63006	52505	61920	57271	52025	41736
All low-level	93149	67027	61279	66512	66130	66750	71698	60886	70301	65934	60669	50419
Elevated point	186	219	220	220	219	219	196	186	187	220	220	219
Total Anthropogenic	8568	8842	8883	8863	8903	9043	8888	8568	8569	8883	8863	8903
TOTAL	**93335**	**67246**	**61499**	**66732**	**66349**	**66969**	**71894**	**61072**	**70488**	**66154**	**60888**	**50639**

CO	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	5093	5116	5116	5116	5116	5116	5100	5093	5093	5116	5116	5116
Motor vehicle	16463	19795	20187	19991	20383	21755	18815	16463	16463	20187	19991	20383
Non-road	12279	11933	11933	11933	11933	11933	12279	12279	12279	11933	11933	11933
Low-level point	1135	1195	1195	1195	1195	1195	1156	1135	1135	1195	1195	1195
All low-level	34970	38039	38431	38235	38627	39999	37350	34970	34970	38431	38235	38627
Elevated point	1779	1869	1877	1874	1871	1868	1794	1779	1787	1877	1874	1871
Total Anthropogenic	36749	39908	40308	40109	40498	41867	39144	36749	36757	40308	40109	40498
TOTAL	**36749**	**39908**	**40308**	**40109**	**40498**	**41867**	**39144**	**36749**	**36757**	**40308**	**40109**	**40498**

Table B-27
Summary of 2007 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 3

NOX	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	262	288	288	288	288	288	271	262	262	288	288	288
Motor vehicle	1231	1480	1510	1495	1524	1627	1407	1231	1231	1510	1495	1524
Non-road	735	924	924	924	924	924	735	735	735	924	924	924
Low-level point	122	135	135	135	135	135	126	122	122	135	135	135
Biogenic	378	336	314	353	377	375	362	363	358	346	327	306
All low-level	2728	3163	3171	3195	3249	3349	2902	2713	2708	3203	3169	3177
Elevated point	1065	1098	1118	1115	1135	1129	1065	1065	1083	1139	1136	1135
Total Anthropogenic	3416	3926	3975	3957	4006	4103	3604	3416	3434	3996	3978	4006
TOTAL	**3793**	**4262**	**4289**	**4310**	**4383**	**4478**	**3967**	**3778**	**3791**	**4342**	**4305**	**4312**

VOC	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	2032	2033	2033	2033	2033	2033	2033	2032	2032	2033	2033	2033
Motor vehicle	797	958	977	967	986	1053	910	797	797	977	967	986
Non-road	576	360	360	360	360	360	576	576	576	360	360	360
Low-level point	253	383	383	383	383	383	285	253	253	383	383	383
Biogenic	33636	25595	21501	26083	28484	28505	29671	24904	25682	25391	24251	16207
All low-level	37293	29329	25254	29826	32246	32334	33475	28562	29340	29144	27994	19969
Elevated point	92	106	106	106	106	106	94	92	93	106	106	106
Total Anthropogenic	3750	3839	3859	3849	3868	3934	3898	3750	3750	3859	3849	3868
TOTAL	**37385**	**29435**	**25360**	**29932**	**32351**	**32439**	**33569**	**28654**	**29433**	**29250**	**28100**	**20074**

CO	070829	070830	070831	070901	070902	070903	070904	070905	070906	070907	070908	070909
Area	1752	1759	1759	1759	1759	1759	1754	1752	1752	1759	1759	1759
Motor vehicle	7921	9524	9712	9618	9806	10466	9052	7921	7921	9712	9618	9806
Non-road	5688	5580	5580	5580	5580	5580	5688	5688	5688	5580	5580	5580
Low-level point	207	227	227	227	227	227	216	207	207	227	227	227
All low-level	15567	17090	17278	17184	17373	18033	16710	15567	15567	17278	17184	17373
Elevated point	878	941	944	943	941	942	884	878	881	944	943	941
Total Anthropogenic	16445	18031	18222	18127	18314	18975	17594	16445	16448	18222	18127	18314
TOTAL	**16445**	**18031**	**18222**	**18127**	**18314**	**18975**	**17594**	**16445**	**16448**	**18222**	**18127**	**18314**

Table B-28
Summary of 2007 Baseline Emissions for June 2001 Episode (tons/day) in Grid 1

NOX	070616	070617	070618	070619	070620	070621	070622
Area	1993	1931	2118	2118	2118	2118	2118
Motor vehicle	6794	5945	7148	7290	7219	7361	7856
Non-road	5728	5728	7179	7179	7179	7179	7179
Low-level point	1761	1717	1847	1847	1847	1847	1847
Biogenic	3468	3466	3640	3313	2979	2964	2958
All low-level	19745	18786	21933	21747	21342	21469	21958
Elevated point	8726	8423	9033	9068	9087	9098	9058
Total Anthropogenic	25002	23744	27326	27502	27450	27603	28058
TOTAL	**28471**	**27209**	**30966**	**30815**	**30429**	**30566**	**31016**

VOC	070616	070617	070618	070619	070620	070621	070622
Area	11332	11331	11335	11335	11335	11335	11335
Motor vehicle	4540	3973	4777	4871	4824	4918	5249
Non-road	5758	5758	3012	3012	3012	3012	3012
Low-level point	1584	1458	2102	2102	2102	2102	2102
Biogenic	132346	140983	155781	121735	96098	83973	78561
All low-level	155561	163502	177007	143055	117371	105341	100259
Elevated point	488	464	526	527	528	529	527
Total Anthropogenic	23703	22984	21752	21847	21800	21896	22225
TOTAL	**156049**	**163967**	**177533**	**143582**	**117898**	**105870**	**100786**

CO	070616	070617	070618	070619	070620	070621	070622
Area	10369	10351	10404	10404	10404	10404	10404
Motor vehicle	42488	37177	44701	45586	45143	46029	49127
Non-road	53313	53313	45385	45385	45385	45385	45385
Low-level point	3495	3391	3718	3718	3718	3718	3718
All low-level	109664	104232	104207	105092	104650	105535	108633
Elevated point	4957	4727	5080	5098	5086	5134	5096
Total Anthropogenic	114621	108960	109287	110190	109736	110669	113729
TOTAL	**114621**	**108960**	**109287**	**110190**	**109736**	**110669**	**113729**

Table B-29
Summary of 2007 Baseline Emissions for June 2001 Episode (tons/day) in Grid 2

NOX	070616	070617	070618	070619	070620	070621	070622
Area	934	903	997	997	997	997	997
Motor vehicle	2907	2544	3059	3119	3089	3149	3361
Non-road	2155	2155	2647	2647	2647	2647	2647
Low-level point	629	614	664	664	664	664	664
Biogenic	1009	1075	1116	1063	980	912	869
All low-level	7635	7291	8483	8491	8377	8370	8539
Elevated point	3432	3416	3483	3522	3543	3547	3522
Total Anthropogenic	10058	9632	10850	10950	10940	11005	11192
TOTAL	**11067**	**10708**	**11966**	**12013**	**11920**	**11917**	**12061**

VOC	070616	070617	070618	070619	070620	070621	070622
Area	4816	4815	4817	4817	4817	4817	4817
Motor vehicle	1947	1704	2048	2089	2069	2109	2251
Non-road	2077	2077	1072	1072	1072	1072	1072
Low-level point	712	643	992	992	992	992	992
Biogenic	82542	93498	100850	76477	61065	50946	43749
All low-level	92094	102737	109780	85447	70015	59937	52882
Elevated point	199	189	220	220	221	222	221
Total Anthropogenic	9751	9428	9150	9191	9171	9213	9353
TOTAL	**92293**	**102926**	**110000**	**85668**	**70236**	**60159**	**53103**

CO	070616	070617	070618	070619	070620	070621	070622
Area	5100	5093	5116	5116	5116	5116	5116
Motor vehicle	18830	16476	19810	20203	20006	20399	21772
Non-road	17671	17671	14984	14984	14984	14984	14984
Low-level point	1158	1138	1202	1202	1202	1202	1202
All low-level	42759	40377	41112	41504	41308	41701	43074
Elevated point	1820	1798	1891	1910	1897	1941	1910
Total Anthropogenic	44579	42175	43003	43414	43205	43641	44984
TOTAL	**44579**	**42175**	**43003**	**43414**	**43205**	**43641**	**44984**

Table B-30
Summary of 2007 Baseline Emissions for June 2001 Episode (tons/day) in Grid 3

NOX	070616	070617	070618	070619	070620	070621	070622
Area	271	262	288	288	288	288	288
Motor vehicle	1406	1230	1479	1509	1494	1523	1626
Non-road	810	810	1015	1015	1015	1015	1015
Low-level point	124	120	135	135	135	135	135
Biogenic	350	389	400	391	374	336	307
All low-level	2961	2812	3318	3338	3306	3298	3372
Elevated point	1094	1087	1136	1153	1166	1164	1147
Total Anthropogenic	3706	3510	4054	4100	4099	4126	4211
TOTAL	**4056**	**3898**	**4454**	**4490**	**4472**	**4462**	**4518**

VOC	070616	070617	070618	070619	070620	070621	070622
Area	2033	2032	2033	2033	2033	2033	2033
Motor vehicle	919	804	967	986	977	996	1063
Non-road	900	900	468	468	468	468	468
Low-level point	289	257	387	387	387	387	387
Biogenic	32242	38969	39530	33605	31571	24887	16452
All low-level	36383	42963	43385	37479	35435	28771	20403
Elevated point	95	93	104	105	105	105	105
Total Anthropogenic	4236	4087	3960	3979	3969	3989	4056
TOTAL	**36478**	**43056**	**43489**	**37584**	**35540**	**28876**	**20508**

CO	070616	070617	070618	070619	070620	070621	070622
Area	1754	1752	1759	1759	1759	1759	1759
Motor vehicle	9056	7924	9528	9716	9622	9811	10471
Non-road	7453	7453	6470	6470	6470	6470	6470
Low-level point	212	203	225	225	225	225	225
All low-level	18476	17332	17981	18170	18076	18264	18925
Elevated point	889	880	939	941	941	945	941
Total Anthropogenic	19364	18212	18920	19111	19016	19210	19866
TOTAL	**19364**	**18212**	**18920**	**19111**	**19016**	**19210**	**19866**

Table B-31
Summary of 2007 Baseline Emissions for July 2002 Episode (tons/day) in Grid 1

NOX	070704	070705	070706	070707	070708	070709	070710
Area	1931	2118	1993	1931	2118	2118	2118
Motor vehicle	5913	7813	6757	5913	7109	7250	7180
Non-road	5644	7055	5644	5644	7055	7055	7055
Low-level point	1717	1847	1761	1717	1847	1847	1847
Biogenic	4236	3944	3766	3962	4238	4206	3747
All low-level	19440	22777	19922	19166	22368	22477	21947
Elevated point	8423	9058	8747	8445	9033	9046	9065
Total Anthropogenic	23627	27892	24903	23649	27163	27317	27265
TOTAL	**27863**	**31836**	**28669**	**27611**	**31401**	**31523**	**31012**

VOC	070704	070705	070706	070707	070708	070709	070710
Area	11331	11335	11332	11331	11335	11335	11335
Motor vehicle	3997	5281	4568	3997	4805	4901	4853
Non-road	5627	2960	5627	5627	2960	2960	2960
Low-level point	1458	2102	1584	1458	2102	2102	2102
Biogenic	145738	141756	139354	149280	157141	141002	119165
All low-level	168151	163435	162464	171692	178344	162300	140415
Elevated point	464	527	488	464	526	527	528
Total Anthropogenic	22877	22206	23599	22877	21729	21825	21778
TOTAL	**168615**	**163962**	**162953**	**172156**	**178870**	**162827**	**140943**

CO	070704	070705	070706	070707	070708	070709	070710
Area	10351	10404	10369	10351	10404	10404	10404
Motor vehicle	37119	49050	42422	37119	44631	45515	45073
Non-road	52108	44374	52108	52108	44374	44374	44374
Low-level point	3391	3718	3495	3391	3718	3718	3718
All low-level	102970	107546	108393	102970	103127	104011	103569
Elevated point	4727	5096	4957	4727	5080	5098	5086
Total Anthropogenic	107697	112643	113351	107697	108207	109109	108655
TOTAL	**107697**	**112643**	**113351**	**107697**	**108207**	**109109**	**108655**

Table B-32
Summary of 2007 Baseline Emissions for July 2002 Episode (tons/day) in Grid 2

NOX	070704	070705	070706	070707	070708	070709	070710
Area	903	997	934	903	997	997	997
Motor vehicle	2523	3334	2884	2523	3034	3094	3064
Non-road	2126	2604	2126	2126	2604	2604	2604
Low-level point	614	664	629	614	664	664	664
Biogenic	1203	1179	1137	1124	1166	1198	1145
All low-level	7368	8778	7710	7290	8465	8557	8473
Elevated point	3416	3522	3454	3438	3483	3501	3521
Total Anthropogenic	9582	11121	10027	9604	10782	10859	10850
TOTAL	**10785**	**12300**	**11164**	**10728**	**11948**	**12057**	**11995**

VOC	070704	070705	070706	070707	070708	070709	070710
Area	4815	4817	4816	4815	4817	4817	4817
Motor vehicle	1721	2274	1967	1721	2069	2110	2090
Non-road	2029	1055	2029	2029	1055	1055	1055
Low-level point	643	992	712	643	992	992	992
Biogenic	87514	90505	90960	92573	96242	92838	76053
All low-level	96723	99644	100484	101782	105176	101813	85007
Elevated point	189	221	199	189	220	220	221
Total Anthropogenic	9397	9359	9723	9397	9153	9195	9175
TOTAL	**96911**	**99865**	**100683**	**101971**	**105395**	**102033**	**85228**

CO	070704	070705	070706	070707	070708	070709	070710
Area	5093	5116	5100	5093	5116	5116	5116
Motor vehicle	16449	21736	18799	16449	19778	20170	19974
Non-road	17273	14659	17273	17273	14659	14659	14659
Low-level point	1138	1202	1158	1138	1202	1202	1202
All low-level	39953	42713	42331	39953	40755	41147	40951
Elevated point	1798	1910	1820	1798	1891	1910	1897
Total Anthropogenic	41751	44624	44151	41751	42646	43057	42848
TOTAL	**41751**	**44624**	**44151**	**41751**	**42646**	**43057**	**42848**

Table B-33
Summary of 2007 Baseline Emissions for July 2002 Episode (tons/day) in Grid 3

NOX	070704	070705	070706	070707	070708	070709	070710
Area	262	288	271	262	288	288	288
Motor vehicle	1218	1610	1392	1218	1465	1494	1479
Non-road	798	998	798	798	998	998	998
Low-level point	120	135	124	120	135	135	135
Biogenic	426	444	438	410	423	438	438
All low-level	2824	3474	3023	2809	3308	3352	3337
Elevated point	1087	1147	1116	1108	1136	1131	1145
Total Anthropogenic	3486	4177	3701	3507	4021	4045	4045
TOTAL	**3911**	**4620**	**4139**	**3917**	**4444**	**4483**	**4482**

VOC	070704	070705	070706	070707	070708	070709	070710
Area	2032	2033	2033	2032	2033	2033	2033
Motor vehicle	814	1076	931	814	979	998	989
Non-road	879	460	879	879	460	460	460
Low-level point	257	387	289	257	387	387	387
Biogenic	32335	42509	45719	40079	41123	41730	38171
All low-level	36317	46466	49851	44062	44982	45609	42040
Elevated point	93	105	95	93	104	105	105
Total Anthropogenic	4076	4061	4227	4076	3964	3983	3974
TOTAL	**36410**	**46570**	**49946**	**44155**	**45086**	**45713**	**42145**

CO	070704	070705	070706	070707	070708	070709	070710
Area	1752	1759	1754	1752	1759	1759	1759
Motor vehicle	7912	10455	9042	7912	9513	9702	9608
Non-road	7288	6331	7288	7288	6331	6331	6331
Low-level point	203	225	212	203	225	225	225
All low-level	17155	18770	18297	17155	17828	18017	17923
Elevated point	880	941	889	880	939	941	941
Total Anthropogenic	18035	19712	19185	18035	18767	18958	18863
TOTAL	**18035**	**19712**	**19185**	**18035**	**18767**	**18958**	**18863**

Table B-34
Summary of 2012 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 1

NOX	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	1942	2131	2131	2131	2131	2131	2005	1942	1942	2131	2131	2131
Motor vehicle	4045	4864	4960	4912	5008	5345	4623	4045	4045	4960	4912	5008
Non-road	4994	6012	6012	6012	6012	6012	4994	4994	4994	6012	6012	6012
Low-level point	1732	1865	1865	1865	1865	1865	1776	1732	1732	1865	1865	1865
Biogenic	3411	3014	3040	3319	3475	3421	3406	3248	3239	3177	3016	2809
All low-level	16124	17886	18007	18238	18491	18774	16803	15960	15951	18145	17936	17825
Elevated point	8120	8685	8666	8683	8725	8698	8368	8120	8142	8688	8705	8725
Total Anthropogenic	20833	23556	23634	23603	23741	24051	21765	20833	20854	23656	23625	23741
TOTAL	**24244**	**26570**	**26674**	**26922**	**27216**	**27473**	**25171**	**24080**	**24093**	**26832**	**26641**	**26550**

VOC	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	11906	11910	11910	11910	11910	11910	11907	11906	11906	11910	11910	11910
Motor vehicle	3028	3640	3713	3676	3749	4001	3460	3028	3028	3713	3676	3749
Non-road	3021	1988	1988	1988	1988	1988	3021	3021	3021	1988	1988	1988
Low-level point	1522	2212	2212	2212	2212	2212	1657	1522	1522	2212	2212	2212
Biogenic	136177	93572	88106	97692	99489	96235	91448	84182	96556	92786	85907	72467
All low-level	155653	113322	107928	117478	119348	116345	111493	103658	116032	112609	105693	92325
Elevated point	472	535	536	536	537	537	496	472	472	536	536	537
Total Anthropogenic	19948	20285	20358	20322	20395	20647	20540	19948	19948	20358	20322	20395
TOTAL	**156125**	**113857**	**108464**	**118014**	**119885**	**116882**	**111988**	**104130**	**116504**	**113145**	**106229**	**92862**

CO	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	10423	10475	10475	10475	10475	10475	10440	10423	10423	10475	10475	10475
Motor vehicle	32316	38857	39626	39241	40011	42704	36933	32316	32316	39626	39241	40011
Non-road	36621	35400	35400	35400	35400	35400	36621	36621	36621	35400	35400	35400
Low-level point	3474	3791	3791	3791	3791	3791	3581	3474	3474	3791	3791	3791
All low-level	82834	88522	89291	88907	89676	92369	87575	82834	82834	89291	88907	89676
Elevated point	4815	5154	5165	5164	5170	5167	5046	4815	4815	5165	5164	5170
Total Anthropogenic	87648	93676	94456	94071	94846	97536	92621	87648	87648	94456	94071	94846
TOTAL	**87648**	**93676**	**94456**	**94071**	**94846**	**97536**	**92621**	**87648**	**87648**	**94456**	**94071**	**94846**

Table B-35
Summary of 2012 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 2

NOX	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	908	1003	1003	1003	1003	1003	940	908	908	1003	1003	1003
Motor vehicle	1684	2025	2065	2045	2085	2226	1925	1684	1684	2065	2045	2085
Non-road	1985	2365	2365	2365	2365	2365	1985	1985	1985	2365	2365	2365
Low-level point	638	688	688	688	688	688	654	638	638	688	688	688
Biogenic	1074	928	880	959	969	960	993	990	1002	952	900	858
All low-level	6288	7008	7000	7060	7109	7241	6496	6205	6216	7072	7001	6998
Elevated point	3372	3439	3433	3449	3467	3454	3363	3372	3393	3455	3470	3467
Total Anthropogenic	8587	9520	9553	9549	9607	9735	8866	8587	8608	9575	9571	9607
TOTAL	**9660**	**10447**	**10433**	**10508**	**10576**	**10695**	**9859**	**9576**	**9610**	**10527**	**10471**	**10465**

VOC	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	5088	5090	5090	5090	5090	5090	5088	5088	5088	5090	5090	5090
Motor vehicle	1280	1539	1569	1554	1584	1691	1462	1280	1280	1569	1554	1584
Non-road	1155	749	749	749	749	749	1155	1155	1155	749	749	749
Low-level point	679	1056	1056	1056	1056	1056	753	679	679	1056	1056	1056
Biogenic	84768	58404	52616	57869	57446	57926	63006	52505	61920	57271	52025	41736
All low-level	92969	66838	61080	66318	65926	66512	71465	60706	70121	65735	60475	50216
Elevated point	195	228	229	229	229	229	205	195	195	229	229	229
Total Anthropogenic	8397	8662	8693	8678	8709	8816	8664	8397	8397	8693	8678	8709
TOTAL	**93164**	**67066**	**61309**	**66547**	**66155**	**66741**	**71670**	**60901**	**70316**	**65964**	**60704**	**50445**

CO	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	5073	5096	5096	5096	5096	5096	5081	5073	5073	5096	5096	5096
Motor vehicle	14274	17163	17503	17333	17673	18863	16314	14274	14274	17503	17333	17673
Non-road	13283	12972	12972	12972	12972	12972	13283	13283	13283	12972	12972	12972
Low-level point	1186	1249	1249	1249	1249	1249	1208	1186	1186	1249	1249	1249
All low-level	33816	36480	36820	36650	36990	38179	35884	33816	33816	36820	36650	36990
Elevated point	1875	1954	1961	1965	1965	1967	1892	1875	1875	1961	1965	1965
Total Anthropogenic	35691	38434	38781	38615	38955	40146	37776	35691	35691	38781	38615	38955
TOTAL	**35691**	**38434**	**38781**	**38615**	**38955**	**40146**	**37776**	**35691**	**35691**	**38781**	**38615**	**38955**

Table B-36
Summary of 2012 Baseline Emissions for August/September 1999 Episode (tons/day) in Grid 3

NOX	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	265	291	291	291	291	291	273	265	265	291	291	291
Motor vehicle	818	984	1003	994	1013	1081	935	818	818	1003	994	1013
Non-road	762	933	933	933	933	933	762	762	762	933	933	933
Low-level point	127	141	141	141	141	141	131	127	127	141	141	141
Biogenic	378	336	314	353	377	375	362	363	358	346	327	306
All low-level	2349	2685	2683	2711	2755	2821	2464	2334	2329	2714	2686	2684
Elevated point	1078	1117	1116	1122	1137	1128	1074	1078	1100	1138	1143	1137
Total Anthropogenic	3050	3466	3485	3480	3515	3574	3175	3050	3071	3506	3502	3515
TOTAL	**3427**	**3801**	**3799**	**3833**	**3892**	**3949**	**3538**	**3412**	**3429**	**3852**	**3829**	**3820**

VOC	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	2144	2144	2144	2144	2144	2144	2144	2144	2144	2144	2144	2144
Motor vehicle	612	735	750	743	757	808	699	612	612	750	743	757
Non-road	544	347	347	347	347	347	544	544	544	347	347	347
Low-level point	269	410	410	410	410	410	304	269	269	410	410	410
Biogenic	33636	25595	21501	26083	28484	28505	29671	24904	25682	25391	24251	16207
All low-level	37204	29232	25152	29727	32142	32214	33362	28473	29251	29042	27894	19865
Elevated point	98	112	113	113	113	113	101	98	98	113	113	113
Total Anthropogenic	3667	3748	3763	3756	3771	3822	3792	3667	3667	3763	3756	3771
TOTAL	**37302**	**29344**	**25265**	**29840**	**32255**	**32327**	**33463**	**28571**	**29349**	**29155**	**28007**	**19978**

CO	120829	120830	120831	120901	120902	120903	120904	120905	120906	120907	120908	120909
Area	1676	1683	1683	1683	1683	1683	1678	1676	1676	1683	1683	1683
Motor vehicle	6982	8395	8561	8478	8644	9226	7979	6982	6982	8561	8478	8644
Non-road	6169	6076	6076	6076	6076	6076	6169	6169	6169	6076	6076	6076
Low-level point	217	238	238	238	238	238	226	217	217	238	238	238
All low-level	15044	16392	16558	16475	16641	17223	16053	15044	15044	16558	16475	16641
Elevated point	935	994	1001	1003	1005	1004	947	935	935	1001	1003	1005
Total Anthropogenic	15979	17386	17559	17478	17646	18227	17000	15979	15979	17559	17478	17646
TOTAL	**15979**	**17386**	**17559**	**17478**	**17646**	**18227**	**17000**	**15979**	**15979**	**17559**	**17478**	**17646**

Table B-37
Summary of 2012 Baseline Emissions for June 2001 Episode (tons/day) in Grid 1

NOX	120616	120617	120618	120619	120620	120621	120622
Area	2005	1942	2131	2131	2131	2131	2131
Motor vehicle	4622	4044	4863	4959	4911	5007	5344
Non-road	5808	5808	7055	7055	7055	7055	7055
Low-level point	1800	1755	1889	1889	1889	1889	1889
Biogenic	3468	3466	3640	3313	2979	2964	2958
All low-level	17703	17015	19578	19347	18965	19046	19377
Elevated point	8910	8633	9304	9286	9303	9322	9296
Total Anthropogenic	23145	22182	25242	25319	25288	25404	25715
TOTAL	**26614**	**25648**	**28882**	**28632**	**28268**	**28368**	**28673**

VOC	120616	120617	120618	120619	120620	120621	120622
Area	11907	11906	11910	11910	11910	11910	11910
Motor vehicle	3472	3038	3653	3725	3689	3761	4014
Non-road	5100	5100	2807	2807	2807	2807	2807
Low-level point	1654	1519	2207	2207	2207	2207	2207
Biogenic	132346	140983	155781	121735	96098	83973	78561
All low-level	154479	162546	176358	142384	116710	104658	99499
Elevated point	501	477	539	540	540	541	541
Total Anthropogenic	22634	22040	21115	21189	21153	21226	21479
TOTAL	**154980**	**163023**	**176897**	**142924**	**117251**	**105199**	**100040**

CO	120616	120617	120618	120619	120620	120621	120622
Area	10440	10423	10475	10475	10475	10475	10475
Motor vehicle	36902	32289	38824	39592	39208	39977	42668
Non-road	56739	56739	48868	48868	48868	48868	48868
Low-level point	3604	3498	3836	3836	3836	3836	3836
All low-level	107685	102948	102002	102771	102387	103155	105846
Elevated point	5101	4871	5210	5220	5220	5225	5222
Total Anthropogenic	112786	107819	107212	107991	107606	108381	111069
TOTAL	**112786**	**107819**	**107212**	**107991**	**107606**	**108381**	**111069**

Table B-38
Summary of 2012 Baseline Emissions for June 2001 Episode (tons/day) in Grid 2

NOX	120616	120617	120618	120619	120620	120621	120622
Area	940	908	1003	1003	1003	1003	1003
Motor vehicle	1925	1684	2025	2065	2045	2085	2226
Non-road	2209	2209	2632	2632	2632	2632	2632
Low-level point	650	634	686	686	686	686	686
Biogenic	1009	1075	1116	1063	980	912	869
All low-level	6733	6511	7462	7450	7346	7318	7416
Elevated point	3513	3519	3609	3603	3618	3615	3602
Total Anthropogenic	9236	8955	9955	9989	9985	10021	10149
TOTAL	**10245**	**10030**	**11071**	**11052**	**10965**	**10933**	**11018**

VOC	120616	120617	120618	120619	120620	120621	120622
Area	5088	5088	5090	5090	5090	5090	5090
Motor vehicle	1472	1288	1549	1579	1564	1595	1702
Non-road	1875	1875	1018	1018	1018	1018	1018
Low-level point	754	680	1056	1056	1056	1056	1056
Biogenic	82542	93498	100850	76477	61065	50946	43749
All low-level	91732	102429	109562	85220	69792	59704	52615
Elevated point	208	197	228	228	229	229	229
Total Anthropogenic	9397	9128	8940	8971	8956	8987	9095
TOTAL	**91939**	**102626**	**109790**	**85448**	**70021**	**59933**	**52844**

CO	120616	120617	120618	120619	120620	120621	120622
Area	5081	5073	5096	5096	5096	5096	5096
Motor vehicle	16289	14253	17137	17477	17307	17646	18834
Non-road	18965	18965	16245	16245	16245	16245	16245
Low-level point	1211	1190	1257	1257	1257	1257	1257
All low-level	41546	39480	39735	40075	39905	40244	41432
Elevated point	1908	1891	1966	1974	1977	1978	1979
Total Anthropogenic	43454	41371	41701	42048	41882	42222	43411
TOTAL	**43454**	**41371**	**41701**	**42048**	**41882**	**42222**	**43411**

Table B-39
Summary of 2012 Baseline Emissions for June 2001 Episode (tons/day) in Grid 3

NOX	120616	120617	120618	120619	120620	120621	120622
Area	273	265	291	291	291	291	291
Motor vehicle	935	818	983	1003	993	1012	1081
Non-road	835	835	1014	1014	1014	1014	1014
Low-level point	130	125	141	141	141	141	141
Biogenic	350	389	400	391	374	336	307
All low-level	2522	2431	2828	2838	2812	2794	2833
Elevated point	1077	1082	1142	1141	1147	1140	1132
Total Anthropogenic	3250	3124	3570	3589	3585	3598	3657
TOTAL	**3599**	**3513**	**3970**	**3980**	**3958**	**3934**	**3965**

VOC	120616	120617	120618	120619	120620	120621	120622
Area	2144	2144	2144	2144	2144	2144	2144
Motor vehicle	705	617	741	756	749	763	815
Non-road	827	827	450	450	450	450	450
Low-level point	307	272	413	413	413	413	413
Biogenic	32242	38969	39530	33605	31571	24887	16452
All low-level	36224	42828	43278	37368	35327	28658	20275
Elevated point	101	99	110	111	111	111	111
Total Anthropogenic	4084	3958	3859	3874	3867	3882	3933
TOTAL	**36326**	**42927**	**43388**	**37479**	**35438**	**28769**	**20386**

CO	120616	120617	120618	120619	120620	120621	120622
Area	1678	1676	1683	1683	1683	1683	1683
Motor vehicle	7961	6966	8376	8541	8458	8624	9205
Non-road	8026	8026	7031	7031	7031	7031	7031
Low-level point	222	213	235	235	235	235	235
All low-level	17887	16880	17325	17491	17408	17574	18154
Elevated point	946	934	988	995	997	999	998
Total Anthropogenic	18833	17814	18313	18486	18405	18573	19153
TOTAL	**18833**	**17814**	**18313**	**18486**	**18405**	**18573**	**19153**

Table B-40
Summary of 2012 Baseline Emissions for July 2002 Episode (tons/day) in Grid 1

NOX	120704	120705	120706	120707	120708	120709	120710
Area	1942	2131	2005	1942	2131	2131	2131
Motor vehicle	4034	5330	4610	4034	4850	4946	4898
Non-road	5727	6941	5727	5727	6941	6941	6941
Low-level point	1755	1889	1800	1755	1889	1889	1889
Biogenic	4236	3944	3766	3962	4238	4206	3747
All low-level	17693	20235	17908	17419	20049	20113	19606
Elevated point	8633	9296	8932	8655	9304	9264	9281
Total Anthropogenic	22091	25587	23074	22112	25115	25171	25140
TOTAL	**26327**	**29531**	**26840**	**26074**	**29353**	**29377**	**28887**

VOC	120704	120705	120706	120707	120708	120709	120710
Area	11906	11910	11907	11906	11910	11910	11910
Motor vehicle	3055	4037	3492	3055	3674	3746	3710
Non-road	4993	2766	4993	4993	2766	2766	2766
Low-level point	1519	2207	1654	1519	2207	2207	2207
Biogenic	145738	141756	139354	149280	157141	141002	119165
All low-level	167212	162676	161400	170753	177696	161631	139757
Elevated point	477	541	501	477	539	540	540
Total Anthropogenic	21950	21460	22546	21950	21095	21169	21132
TOTAL	**167689**	**163216**	**161901**	**171230**	**178236**	**162171**	**140297**

CO	120704	120705	120706	120707	120708	120709	120710
Area	10423	10475	10440	10423	10475	10475	10475
Motor vehicle	32252	42618	36859	32252	38779	39547	39163
Non-road	55453	47776	55453	55453	47776	47776	47776
Low-level point	3498	3836	3604	3498	3836	3836	3836
All low-level	101625	104705	106357	101625	100866	101634	101250
Elevated point	4871	5222	5101	4871	5210	5220	5220
Total Anthropogenic	106496	109928	111458	106496	106076	106854	106470
TOTAL	**106496**	**109928**	**111458**	**106496**	**106076**	**106854**	**106470**

Table B-41
Summary of 2012 Baseline Emissions for July 2002 Episode (tons/day) in Grid 2

NOX	120704	120705	120706	120707	120708	120709	120710
Area	908	1003	940	908	1003	1003	1003
Motor vehicle	1672	2209	1911	1672	2010	2050	2030
Non-road	2181	2592	2181	2181	2592	2592	2592
Low-level point	634	686	650	634	686	686	686
Biogenic	1203	1179	1137	1124	1166	1198	1145
All low-level	6597	7669	6818	6519	7457	7529	7456
Elevated point	3519	3602	3534	3541	3609	3581	3597
Total Anthropogenic	8914	10092	9215	8936	9900	9912	9908
TOTAL	**10117**	**11271**	**10352**	**10060**	**11066**	**11110**	**11053**

VOC	120704	120705	120706	120707	120708	120709	120710
Area	5088	5090	5088	5088	5090	5090	5090
Motor vehicle	1300	1718	1485	1300	1563	1594	1578
Non-road	1835	1004	1835	1835	1004	1004	1004
Low-level point	680	1056	754	680	1056	1056	1056
Biogenic	87514	90505	90960	92573	96242	92838	76053
All low-level	96416	99372	100123	101476	104954	101581	84780
Elevated point	197	229	208	197	228	228	229
Total Anthropogenic	9100	9096	9371	9100	8940	8971	8956
TOTAL	**96614**	**99601**	**100331**	**101673**	**105182**	**101809**	**85009**

CO	120704	120705	120706	120707	120708	120709	120710
Area	5073	5096	5081	5073	5096	5096	5096
Motor vehicle	14194	18756	16221	14194	17066	17404	17235
Non-road	18539	15893	18539	18539	15893	15893	15893
Low-level point	1190	1257	1211	1190	1257	1257	1257
All low-level	38995	41002	41052	38995	39312	39650	39481
Elevated point	1891	1979	1908	1891	1966	1974	1977
Total Anthropogenic	40886	42981	42960	40886	41279	41624	41458
TOTAL	**40886**	**42981**	**42960**	**40886**	**41279**	**41624**	**41458**

Table B-42
Summary of 2012 Baseline Emissions for July 2002 Episode (tons/day) in Grid 3

NOX	120704	120705	120706	120707	120708	120709	120710
Area	265	291	273	265	291	291	291
Motor vehicle	808	1068	924	808	972	991	981
Non-road	823	997	823	823	997	997	997
Low-level point	125	141	130	125	141	141	141
Biogenic	426	444	438	410	423	438	438
All low-level	2447	2940	2588	2431	2823	2857	2847
Elevated point	1082	1132	1099	1103	1142	1120	1125
Total Anthropogenic	3103	3628	3248	3124	3542	3539	3535
TOTAL	**3529**	**4072**	**3686**	**3534**	**3965**	**3977**	**3973**

VOC	120704	120705	120706	120707	120708	120709	120710
Area	2144	2144	2144	2144	2144	2144	2144
Motor vehicle	623	823	712	623	749	764	756
Non-road	809	443	809	809	443	443	443
Low-level point	272	413	307	272	413	413	413
Biogenic	32335	42509	45719	40079	41123	41730	38171
All low-level	36182	46333	49691	43927	44872	45494	41928
Elevated point	99	111	101	99	110	111	111
Total Anthropogenic	3946	3935	4073	3946	3859	3875	3868
TOTAL	**36281**	**46444**	**49793**	**44025**	**44982**	**45605**	**42039**

CO	120704	120705	120706	120707	120708	120709	120710
Area	1676	1683	1678	1676	1683	1683	1683
Motor vehicle	6918	9142	7907	6918	8319	8483	8401
Non-road	7849	6881	7849	7849	6881	6881	6881
Low-level point	213	235	222	213	235	235	235
All low-level	16656	17942	17656	16656	17118	17283	17200
Elevated point	934	998	946	934	988	995	997
Total Anthropogenic	17590	18940	18601	17590	18106	18278	18198
TOTAL	**17590**	**18940**	**18601**	**17590**	**18106**	**18278**	**18198**

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EFFECTS OF GROWTH IN VMT AND NEW MOBILE SOURCE EMISSION STANDARDS ON NO_x AND VOC EMISSIONS IN TENNESSEE 1999-2030 (Based on MOBILE6-Final Version)

by

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ABSTRACT

The relative importance of on-road emissions as a participant in ozone formation depends in large part on the total vehicle miles traveled (VMT) per day in a given area. In the future, the relative importance of on-road emissions will be affected by the growth in VMT, which results in increased emissions, and the implementation of motor vehicle emissions controls, which will reduce the emissions associated with each mile of travel. This study evaluates the combined effects of VMT growth and the national LEV, HDDVNO_x, Tier2/Sulfur and HDDV/Sulfur vehicle emission standards on NO_x and VOC emissions for the State of Tennessee utilizing the final version of MOBILE6.

The new LEV, HDDVNO_x, Tier2/Sulfur and HDDV/Sulfur standards, which will be fully in-place by 2001, 2004, 2006, and 2007, respectively, will significantly reduce the emissions of NO_x and VOC from individual on-road vehicles. The implementation of the new regulations will have less effect on VOC emissions compared to NO_x emissions. There is an 80% reduction in NO_x emissions and a 61% reduction in VOC emissions without an I/M program compared to a reduction of 87% in NO_x emissions and 70% reduction in VOC emissions with an I/M program by year 2025. On the other hand, the year-to-year emission reduction with and without an I/M program is 2% to 42% for NO_x emissions and 21 to 39% reduction for VOC emissions for 1999 and 2030, respectively.

With the potential of increasing NO_x and VOC emissions in the future due to increasing growth of DVMT, there is a need to develop strategies which will decrease the current growth rate of DVMT, improve emission control technologies, and/or utilize alternative lesser polluting vehicles in order to maintain the lower emissions which will be achieved during the next 10 to 15 years.

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CHAPTER 1

INTRODUCTION

On-road vehicular traffic is a significant source of air pollution emissions, particularly with regard to the emission of Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs). These pollutants, commonly referred to as ozone precursor pollutants, are photochemically reactive, and thus participate in the formation of ozone. The relative importance of on-road emissions as a participant in ozone formation depends in large part on total vehicle miles traveled (VMT) per day in a given area. In 1998, on-road vehicles were responsible for 32% and 14% of the nationwide emissions of NO_x and VOCs, respectively (1). In the future the relative importance of on-road emissions will be affected by the growth in VMT, which will result in increased emissions, and the implementation of improved motor vehicle emission controls, which reduce the emissions associated with each mile of travel.

The objective of this study was to develop a mobile source emission inventory by county for the State of Tennessee. The mobile source emission inventory utilized the final version of the U.S.EPA MOBILE6 (January 2002). MOBILE6 generates emission factors in terms of grams/mile of travel. These factors are then multiplied by the daily vehicle miles traveled (DVMT) to determine highway emissions in terms of mass/day. Emission calculations were made for the base year of 1999 and for future years out to 2030 and included the effects of all promulgated on-road mobile source emission standards. The effect of Inspection and Maintenance (I/M) programs on emissions was also included for all counties which currently require I/M.

CHAPTER 2

BACKGROUND

Estimation of the emissions for on-road motor vehicle is important as the values are used to develop regional emission inventories which gives an indication of progress made toward meeting (or maintaining compliance with) ambient air quality standards. It is also used to determine if regional transportation plans and projects are consistent with, and conform to, the State Implementation Plan (SIP) (2). This section explains the need for generating emission inventories by reviewing literature published.

2.1. CONFORMITY REQUIREMENTS

According to the Clean Air Act Amendments (CAAA) of 1990, transportation conformity is a way to ensure Federal funding and approval are given to those transportation activities that are consistent with air quality goals and to ensure that the transportation activities do not worsen air quality or interfere with the "purpose" of the SIP, which is to meet the National Ambient Air Quality Standard (NAAQS) (3).

Transportation conformity applies to all EPA-designated nonattainment and maintenance areas (areas previously designated nonattainment and subsequently redesignated to attainment) for transportation related criteria or precursor pollutants. Criteria pollutants include ozone, carbon monoxide (CO), nitrogen dioxide (NO_2), and particles with an aerodynamic diameter less than or equal to 10 microns (PM-10). Precursor pollutants include volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in ozone nonattainment areas, NO_x in nitrogen dioxide (NO_2) areas, and VOC, NO_x and particulate matter in PM-10 areas (3).

The Metropolitan Planning Organizations (MPOs) are required to conduct transportation conformity analyses in their long range transportation plan for areas within MPO planning areas. The State Departments of Transportation (DOT) are responsible for planning and conformity outside the MPO areas. Figure 2-1 shows the transportation conformity process. One of the major requirements of the transportation conformity process includes regional emissions analysis to assess the impacts that transportation investments will have on emissions within the nonattainment or maintenance area (3). The latest EPA-approved emissions models (e.g., MOBILE5b and MOBILE6 for all states other than California and EMFAC7F and EMFAC7G for California) must be used to estimate regional emissions.

2.2. MOBILE MODEL

The Clean Air Act (CAAA) of 1990 included new lower emission standards for on-road vehicles. As a result, the U.S. Environmental Protection Agency (EPA) was required to revise and improve the predictive capability of the highway vehicle emission factor model (2). The highway vehicle emission factor model, MOBILE, is an analytical tool that calculates emissions from highway mobile sources. MOBILE is a Fortran program that provides average in-use fleet emission factors for three criteria pollutants (volatile organic compounds (VOC); carbon monoxide (CO); and oxides of nitrogen (NO_x)), for each of twenty eight categories of vehicles, for any calendar year between 1952 and 2050 and under various conditions affecting the emission levels (e.g., temperatures, speeds) specified by the model user for more detailed and specific modeling requirements.

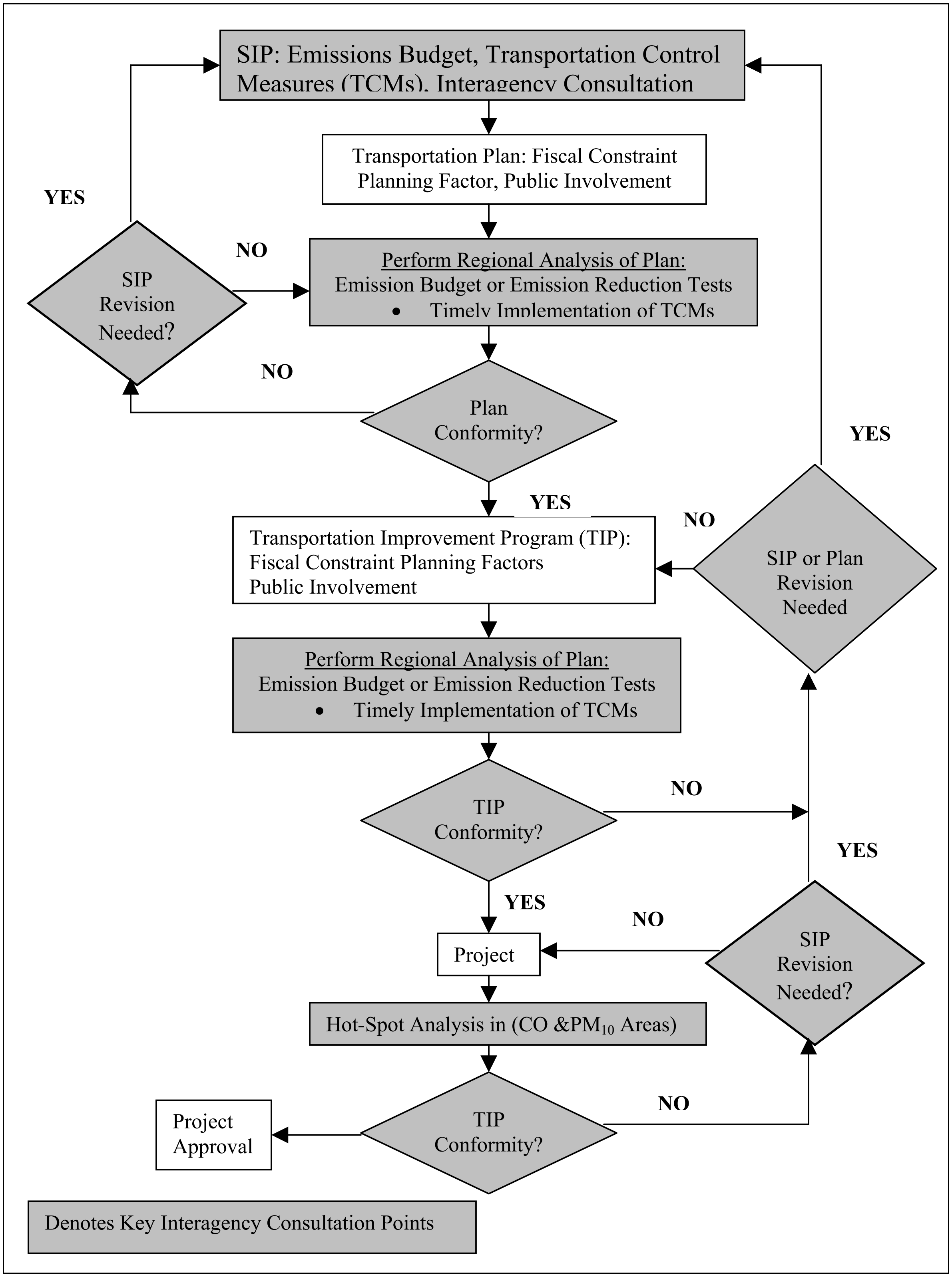

Figure 2-1. Transportation Conformity Process (U.S DOT, 2000)

The output from the model is in the form of emission factors expressed in terms of grams per vehicle miles traveled (g/mi). Thus, emission factors from MOBILE can be combined with estimates of total vehicle miles traveled (VMT) to develop highway vehicle emission inventories (in terms of mass per day, per month, per season, or per year) (4). EPA's MOBILE model has become more sophisticated in its approach to modeling average in-use emissions and has provided the model user with additional options for estimating emission factors for specific times and geographic locations. A brief history of the Mobile model and its development is tabulated in Table 2-1.

2.3. REGULATORY STATUS OF MOBILE SOURCE EMISSION CONTROLS

Four regulations have been promulgated in the U.S. that will reduce emissions from on-road vehicles during the next ten years. These include the National Low Emission Vehicle (NLEV) Standards for Light-Duty Gasoline-Fueled Vehicles, the 2004 NO_x Standards for Heavy-Duty Diesel Engines, the Tier 2/Sulfur Standards and the HDDV Sulfur Standard. These regulations are described briefly below. Table 2-2 shows a schedule for implementation of each of the regulations.

2.3.1. National Low Emission Vehicle (NLEV) Standards

The NLEV program, signed into law in March 1998, was patterned after the California LEV program that went into effect in 1997. The NLEV program was initially implemented in nine northeastern states that were a part of the Ozone Transport Region as follows (5, 6, 7):

Table 2-1. Brief History of the MOBILE Model (U.S. EPA, April 1999)

MOBILE MODEL	UPDATES
MOBILE1 (1978)	First model for highway vehicle emission factor that includes modeling of exhaust emission rates as function of vehicle age/mileage (zero-mile levels and deterioration rates)
MOBILE2 (1981)	Updated with substantial data (available for the first time) on emission controlled vehicles (i.e., catalytic converters, model years 1975 and later) at higher ages/mileages; provided additional use control of input options
MOBILE3 (1984)	Updated with substantial new in-use data; elimination of California vehicle emission rates (continue to model low- and high-altitude emissions); addition of tampering (rates and associated emission impacts) and anti-tampering program benefits; in-use emission factor estimates for non-exhaust emissions adjusted for "real world" fuel volatility as measured by Reid Vapor Pressure (RVP)
MOBILE4 (1989)	Updated with in-use data; addition of running losses as distinct emission source from gasoline powered vehicles; model fuel volatility (RVP) effects on exhaust emission rates; continued expansion of user controlled options for input data
MOBILE4.1 (1991)	Updated with new in-use data; addition of numerous features allowing user control of more parameters affecting in-use emission levels; including more inspection/maintenance (I/M) program design; inclusion of effect of various new emission standards and related regulatory changes (e.g., test procedures); inclusion of impact of oxygenated fuels (e.g., gasohol) on CO emissions
MOBILE5&5a (1993)	Updated with new in-use data; including basing new basic emission rate equation on much larger database derived from State implemented IM240 test programs; include effects of new evaporative emission test procedure (impact on in-use non-exhaust emission levels); include effects of reformulated gasoline (RFG); include effects of new NOx standard of 4.0 g/bhp-hr for heavy duty engines; inclusion of impact of oxygenated fuels on HC emissions; inclusion of Tier 1 emission standards under 1990 Clean Air Act Amendments; addition of July 1 evaluation option; inclusion of impact of low emitting vehicle (LEV) programs patterned after California regulations; revision to speed corrections used to model emission factor over range of traffic speeds. MOBILE5a was issued about 4 months after MOBILE5 to correct a number of minor errors detected under certain specific conditions, and as of today continues to be the "latest official release" of the highway vehicle emission factor model

Table 2-1. Continued.

MOBILE MODEL	UPDATES
MOBILE5b (1996)	Updated to reflect impacts on new regulations promulgated since release of MOBILE5 and MOBILE5a, including: onboard refueling vapor recovery systems, detergent gasoline additives, and Phase II reformulated gasoline (RFG) requirements; reactivates calculation of idle emission factors and expands calendar year range for which emission factors can be calculated from 2020 to 2050; greatly increases flexibility of modeling of inspection/maintenance (I/M) programs, providing for easier modeling of retest based hybrid I/M programs, evaporative emission system pressure and purge test, technician training and certification (TTC) credits, and acceleration simulation mode (ASM) tests (ASM1 and ASM2); corrects phase-in of emission benefits for first cycle of I/M program operation.
MOBILE6 (January 2002)	Updated to include facility based emission factor estimates (different average emission for different roadway types, even at similar average speeds), needed for transportation conformity determinations and more sophisticated application of results (e.g., photochemical air quality modeling, as versus simple inventory tabulation); "real-time" diurnal emission factors; updates on effects of oxygenated fuels on CO emissions; and effects of in-use fuel sulfur content on all emissions; separation of "start" and "running" emissions, to permit more precise temporal and spatial allocation of emissions; updates to many other areas on basis of new data. The model incorporates the effects of the most recent regulations: LEV, Tier2/Sulfur, HDDVNO$_x$ and HDDV/Sulfur Fuel for future year emissions, as discussed in the next section. Includes additional options for I/M programs, etc.

TABLE 2-2. Relative Phase-in of Various Mobile Source Emission Standards

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010 + later
NLEV	Northeastern States		Nationwide									
	30% Tier 1 40% TLEV 30% LEV	40% TLEV 60% LEV	100% LEV	100% LEV	100% LEV	100% LEV	100% LEV					
	Applies to LDV less than 6000 lb Gross vehicle weight (GVW).											
HDDVNO_x						Applies to HDDV. Begins in year 2004.						
Tier 2						LDGV & LLDT (< 6000 lb GVW)- Phase-in begins	LDGV & LLDT- Complete phase in by year 2007.			HLDT & MDPV- Phase-in begins.	HLDT & MDPV- Complete Phase-in	→
Sulfur in Gasoline						Meet Avg: 120ppm; Cap: 300ppm	Phase-in; lower sulfur content	Meet Avg: 30ppm; Cap: 80ppm	→	→	→	→
Sulfur in Diesel								Meet Avg: 15 ppm	→	→	→	→

LDV: Light duty vehicles
LDGV: Light Duty Gasoline Vehicles
LLDT: Light light Duty Trucks (< 6000 lb GVW); HLDT: Heavy Light Duty Trucks (> 6000 and <8500 lb GVW)
MDPV: Medium Duty Passenger Vehicles- SUVs and minivans between 8500 and 10,000 lb GVW.

1999: 30% Tier 1, 40% TLEV, 30% LEV

2000: 0% Tier 1, 40% TLEV, 60% LEV

2001+: 100% LEV

where TLEV refers to a transitional low emission vehicle status. All other states, as shown in Table 2-2, were required to fully participate in the NLEV program beginning in year 2001. Consequently, beginning in 2001, all new cars and light-duty trucks up to 6000 pounds gross vehicle weight have to meet the National Low Emission Vehicle standards. The NLEV NO_x emission standard for light duty vehicles is 0.20 g/mile. This is a 50% reduction from the existing Tier 1 standard of 0.40 g/mile that was phased in nationally in the period of 1994-1996. The TLEV standard for NO_x remained the same as the Tier 1 standard. The NLEV VOC emission standard is 0.075 g/mi of non-methane organic gases (approximately a 70% reduction from the Tier 1 standard of 0.25 g/mile). The TLEV standard for VOCs was 0.125 g/mi. The NLEV standards remain in effect until they are replaced by the Tier 2/Sulfur standards that begin to phase-in beginning in 2004.

2.3.2. 2004 NO_x Standard for Heavy-Duty Diesel Engines

The U.S. EPA promulgated a new NO_x Standard for Heavy-Duty Diesel Engines to take effect beginning in model year 2004. The Standard is referred to in this study as $HDDVNO_x$. The new rule has a combined emission standard for NO_x emissions and non-methane hydrocarbons (NMHC). As per the rule, the manufacturers of such engines have the choice of certifying their new engines to either a 2.4 g/bhp-hr NMHC plus NO_x

standard, or to a 2.5 g/bhp-hr NMHC plus NO_x standard with a limit of 0.5 g/bhp-hr for NMHC. This standard is expected to reduce the NO_x emissions from highway heavy-duty engines by almost 50% (8).

2.3.3. Tier 2 Vehicle Emission Standard and Gasoline Sulfur Requirements

The Tier 2 standard and the sulfur rule were promulgated to help reduce both ozone and particulate matter (PM) levels. This rule treats both vehicles and fuels as a single system resulting in cleaner vehicles using fuels with lower sulfur content. Tier 2 Vehicle Emission Standards, to be phased in beginning in 2004, will apply to all new passenger cars, light trucks and medium-duty passenger vehicles. Light trucks consist of Light Light-Duty Trucks (LLDTs) that are less than 6000 pound gross vehicle weight and Heavy Light-Duty Trucks (HLDTs) that are greater than 6000 pound gross vehicle weight. Medium-Duty passenger vehicle (MDPV) is a new category of cars in the Tier 2 standard that includes SUVs, and passenger vans with between 8500 to 10000 pound gross vehicle weight. For passenger cars and LLDTs, the standards will be phased in over a three year period (2004-2007). For HLDTs and MDPVs, the phase-in begins in the year 2008 with 100% phase-in by year 2009. Upon completion of the phase-in period, all new passenger cars, LLDTs, HLDTs and MDPVs would be subjected to the same set of emission standards.

The other requirement of this rule is the restriction on the sulfur content of gasoline. It affects all gasoline-fueled vehicles that have a catalytic converter, regardless of vehicle age. All refineries will be required to meet the average gasoline sulfur standard of 120 ppm and a cap of 300 ppm beginning in 2004. By 2006, an average of no more than 30 ppm sulfur with a cap of 80 ppm must be met (9). The combined effect of the Tier 2/Sulfur rule is to reduce NO_x emissions to an average of 0.07 grams per mile (9) for new vehicles. The rule does not have a significant effect on VOC emissions.

2.3.4. Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirement

The Heavy-Duty Engine and Vehicle emission standards and the sulfur rule were promulgated to help reduce both ozone and particulate matter (PM) levels. The U.S EPA is establishing a comprehensive national control program that will regulate the heavy-duty vehicle and its fuel as a single system (10). As a part of this program, new emission standards for heavy-duty engines and vehicles will begin to take effect in model year 2007. These standards are based on the use of high-efficiency catalytic exhaust emission control devices or comparably effective advanced technologies (11).

The other requirement of this rule is the restriction on the sulfur content of diesel fuel. Sulfur in diesel fuel must be lowered to enable the high-efficiency catalytic exhaust emission control devices or comparably effective advanced technologies to be effective. In order to meet these more stringent standards for diesel engines, a 97% reduction in the sulfur content of highway diesel fuel from its current level of 500 ppm to 15 ppm is to be implemented (10). Refiners will be required to start producing diesel fuel for use in highway vehicles beginning June 1, 2006.

2.4. GROWTH OF VEHICLE MILES TRAVELED (VMT) IN TENNESSEE

The relative importance of on-road emissions as a participant in ozone formation depends in large part on the total VMT per day in a given area. In the future, the relative importance of on-road emissions will be affected by the growth in VMT, which results in increased emissions, and the implementation of motor vehicle emission controls, which reduce the emissions associated with each mile of travel. While current VMT data compiled by DOTs provides the basis for estimating current emissions, it is necessary to estimate the growth in VMT in order to predict future on-road emissions. This chapter provides the basis for the estimation of the growth rate in VMT for the State of Tennessee on a county-level basis for the period of 1999-2030.

2.4.1. Statewide VMT Equations and Growth

The statewide vehicle miles traveled (VMT) was obtained from the Federal Highway Administration's annual report *Highway Statistics Series* that is available at the FHWA website: www.fhwa.dot.gov/ohim/ohimstat.htm for 1967 through 1999. All statewide VMT are reported as annual vehicle miles traveled by functional road classification for both urban and rural area.

Based on the data available in the *Highway Statistic Series* the state wide annual VMT for Tennessee is summarized in Table 2-3 and shown graphically in Figure 2-2. An analysis of the data indicated that VMT growth in Tennessee was not linear, but generally grew at a compound rate of 3.5% between 1967 and 1999. Since county wide data by roadway classification (rural and urban) were only available for the ten year period of

Table 2-3. State Wide Annual VMT (million mi)

Year	VMT (million mi)
1967	18002
1968	18824
1969	19236
1970	20719
1971	27224
1972	29830
1973	32513
1974	31442
1975	32926
1976	31579
1977	32949
1978	34562
1979	34084
1980	33505
1981	34729
1982	34793
1983	36261
1984	36523
1985	36307
1986	39521
1987	42126
1988	44193
1989	45639
1990	46024
1991	47267
1992	49994
1993	52112
1994	54524
1995	56214
1996	58435
1997	60526
1998	62562
1999	64755

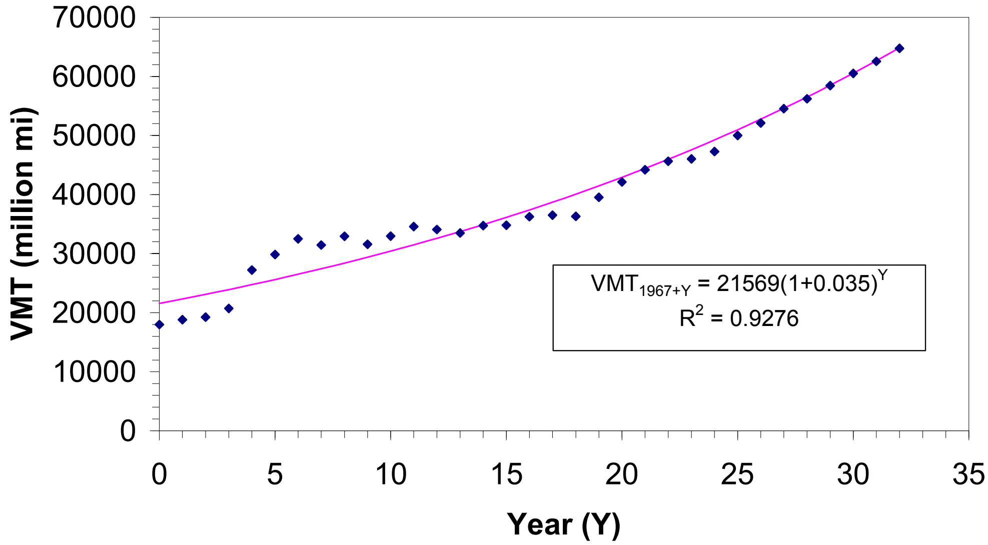

Figure 2-2. State Wide Annual VMT vs Year (1967-1999)

1990-1999 at the on-set of this study, the statewide annual VMT growth rate was recalculated to be 3.9% for that period and is shown in Figure 2-3(a). The best-fit equation for VMT (based on the annual compound growth) is of the following form:

$$VMT_{1990+Y} = K\left(1+\frac{r}{100}\right)^{Y} \tag{2.1}$$

where

VMT_{1990+Y} is the Annual Vehicle Miles Traveled in the 1990 + Y year

r is the growth rate in percent such that the fractional growth is $r/100$

K is a constant associated with the best fit

Y is the number of years since 1990, i.e. if Y= 8, then $VMT_{1990+Y} = VMT_{1998}$

R^2 is the coefficient of determination for the best fit

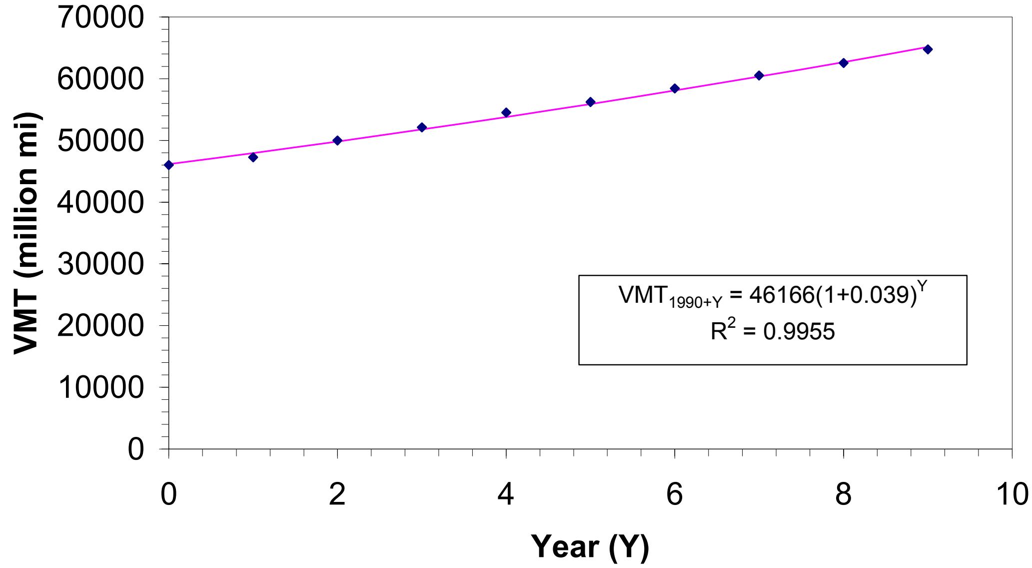

Figure 2-3(a). State Wide Annual VMT vs Year (1990-1999) (compound fit)

All annual VMT values include the VMT contribution from the local traffic category since these were included as an estimate in the FHWA report. The best fit equation is shown in Figure 2-3(a) for the 1990 through 1999 period.

While the statewide growth rate in VMT over the 32 year period (1967-1999) is more of a compound growth rate (a non-linear increase), it is less clear as to whether the last 10 years is more of a linear increase or a compound increase as shown in Figure 2-3. Based on the current practice employed by the Tennessee Department of Transportation (TDOT) and their recommendation, future year VMT for use in this study were estimated by developing a linear best fit to the VMT data for the period 1990-1999 followed by a linear extrapolation of the best fit line for future years. The data in Figure 2-3(a) (1990-

1999) were re-analyzed to determine the linear best fit as shown in Figure 2-3(b), where it can be seen that the least squares fit yields an equation with a R^2 of 0.9985.

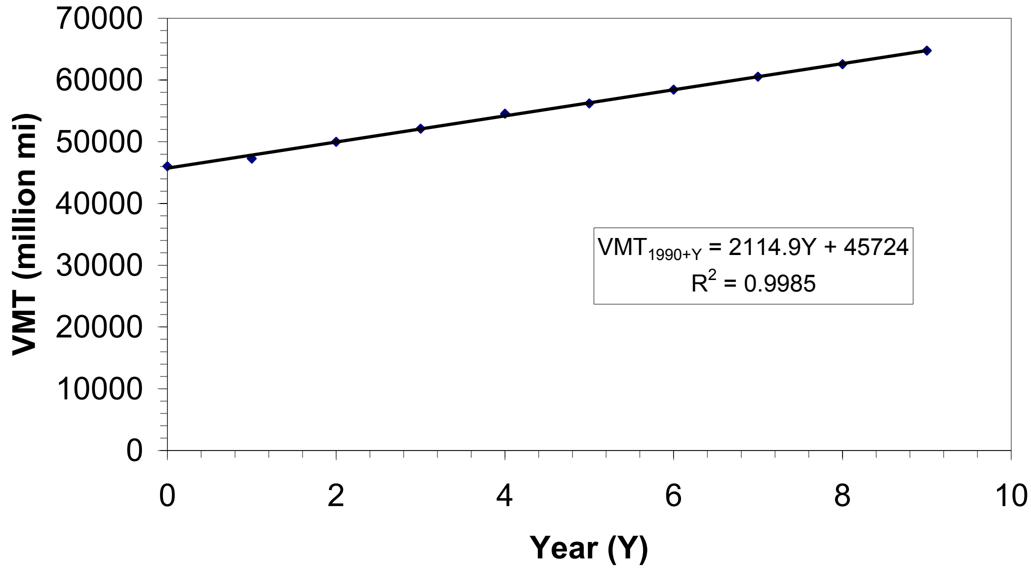

Figure 2-3(b). State Wide Annual VMT vs Year (1990-1999) (linear fit)

The linear equation has the following form:

$$VMT_{1990+Y} = m\,(Y) + b$$

where

'VMT_{1990+Y}' is the annual vehicle miles traveled in the (1990+Y) year

'm' is the slope of the line (increase in VMT per year) in units same as VMT

'Y' is the number of years since 1990

'b' is the intercept of the line, and is equivalent to the best fit value of the annual VMT for the base year of 1990.

In Figure 2-3(b), the linear equation implies that the statewide annual VMT increases by 2,115 million miles/year each year (the slope of the line). Thus, to obtain a future year VMT, this constant value would be added to the then current year's annual VMT. For example, the predicted annual VMT in the year 2000 is obtained by adding 2,115 million miles to the 1999 annual VMT (65,732 million miles), which results in 67,847 million miles. This is essentially a linear extension of the VMT curve shown in Figure 2-3(b) and is consistent with current TDOT practice for projecting VMT. An annual growth rate may be calculated by comparing this increase in VMT to the actual VMT for 1999; this yields a growth rate of 3.2% between 1999 and 2000. However, it must be remembered that this growth rate cannot be considered as being constant, since the actual growth rate decreases in future years (i.e., adding a constant VMT to each successive year's VMT results in a smaller percentage increase in each successive year). Hence in this report, the growth is referred to in terms of the actual increase in the vehicle miles traveled rather than as a percentage.

2.4.2. County Level DVMT Equations and Growth

The county level VMT data were obtained from the annual summaries of *TN Vehicle of Travel* and *TN Vehicle Miles of Travel by County* that were prepared by the Tennessee Department of Transportation (TDOT) each year. The data include 1990-1999, with the exception of 1997 (not available), and were reported as daily vehicle miles traveled (DVMT) by county by functional road classification for both urban and rural areas.

Linear least squares analyses were conducted to determine the increase in DVMT for each county. The additional increase in DVMT each year for each county, represented by the slope m, is summarized in Table 2-4. The concept of the equations is the same as described in the previous section, except that all equations are for DVMT (miles/day) rather than annual VMT. The DVMT equation includes the contribution from local DVMT even though this category is not directly measured by TDOT. The inclusion of local traffic does not affect the calculation of the growth, however, since local traffic is generally estimated by TDOT to be a fraction of the other categories. In Table 2-4, the equations for DVMT on a county level generally had R^2 values in the 0.8+ range.

Growth of DVMT for 1990-1999 for Davidson, Hamilton, Knox, Shelby, and Sullivan Counties are shown in Figures 2-4 to 2-8, respectively. The figures indicate that the linear equation provided a reasonable fit for the data with R^2 values ranging from 0.68 to 0.99. The actual increases in DVMT per year were 716,728; 300,461; 411,509; 828,327 and 132,975 miles/day for these counties, respectively. Figure 2-9 shows a state map by county indicating the increase in DVMT per year (in thousands) for each county to provide a visual indication of the VMT growth occurring in various regions within Tennessee.

Table 2-4. Summary of Linear Equations for Growth Rates for TN Counties, based on 1990-1999 DVMT Data

County	Slope, m	Intercept, b	R^2
Anderson	47,045	1,816,509	0.9
Bedford	32,900	625,948	0.91
Benton	22,128	499,811	0.86
Bledsoe	6,056	188,025	0.87
Blount	91,187	1,602,304	0.98
Bradley	71,732	1,899,588	0.92
Campbell	57,458	1,248,640	0.92
Cannon	8,198	236,157	0.95
Carroll	20,206	603,916	0.77
Carter	25,710	978,321	0.71
Cheatham	43,897	775,975	0.89
Chester	12,664	273,946	0.98
Claiborne	26,138	541,053	0.92
Clay	3,831	133,865	0.78
Cocke	35,699	897,436	0.95
Coffee	56,752	1,502,533	0.96
Crockett	14,920	326,485	0.93
Cumberland	78,792	1,400,316	0.95
Davidson	716,728	14,078,580	0.96
Decatur	22,456	315,150	0.9
DeKalb	12,052	305,076	0.98
Dickson	45,447	1,133,510	0.86
Dyer	27,526	946,115	0.93
Fayette	50,435	965,663	0.94
Fentress	12,046	302,795	0.89
Franklin	13,850	699,144	0.79
Gibson	24,941	961,331	0.98
Giles	40,014	847,358	0.97
Grainger	23,632	423,741	0.94
Greene	85,848	1,653,993	0.95
Grundy	10,122	368,276	0.76
Hamblen	46,871	1,245,577	0.92
Hamilton	300,461	7,144,386	0.99
Hancock	3,666	77,097	0.79
Hardeman	15,511	554,086	0.91
Hardin	20,919	485,599	0.89
Hawkins	25,477	917,705	0.85
Haywood	34,267	889,884	0.9
Henderson	61,803	965,509	0.92
Henry	21,242	664,217	0.86
Hickman	34,095	590,737	0.81
Houston	4,373	104,428	0.83
Humphreys	30,015	633,261	0.99
Jackson	5,913	202,893	0.69
Jefferson	79,423	1,455,403	0.97
Johnson	9,254	280,772	0.83
Knox	411,509	8,563,152	0.97
Lake	640	108,009	0.17
Lauderdale	10,771	531,515	0.56
Lawrence	31,536	628,509	0.98
Lewis	6,853	145,033	0.96
Lincoln	16,460	621,224	0.86
Loudon	56,676	1,415,941	0.95
McMinn	64,858	1,547,783	0.95
McNairy	24,440	594,817	0.93

County	Slope, m	Intercept, b	R^2
Macon	8,399	298,821	0.65
Madison	123,307	2,346,684	0.95
Marion	69,848	1,294,809	0.93
Marshall	31,915	658,533	0.97
Maury	81,553	1,683,500	0.97
Meigs	3,661	215,991	0.44
Monroe	35,122	825,005	0.97
Montgomery	111,856	2,176,782	0.98
Moore	2,765	118,324	0.78
Morgan	8,843	309,912	0.81
Obion	21,524	816,412	0.84
Overton	19,284	373,745	0.95
Perry	8,728	153,473	0.93
Picket	4,625	75,051	0.93
Polk	10,821	368,340	0.67
Putnam	89,483	1,697,275	0.98
Rhea	15,853	554,354	0.85
Roane	37,885	1,583,967	0.89
Robertson	85,315	1,511,482	0.84
Rutherford	222,200	3,305,138	0.95
Scott	16,696	328,538	0.91
Sequatchie	14,077	227,579	0.97
Sevier	97,464	1,640,204	0.91
Shelby	828,327	16,160,069	0.94
Smith	34,866	724,139	0.96
Stewart	7,959	240,069	0.89
Sullivan	132,975	3,176,752	0.68
Sumner	118,906	2,102,851	0.86
Tipton	29,340	712,451	0.93
Trousdale	4,216	172,363	0.8
Unicoi	17,709	327,823	0.93
Union	9,399	234,228	0.95
Van Buren	7,809	99,473	0.95
Warren	23,547	746,824	0.95
Washington	89,651	1,989,188	0.93
Wayne	12,552	264,700	0.93
Weakley	16,721	644,750	0.75
White	20,624	404,390	0.93
Williamson	157,618	2,337,057	0.94
Wilson	122,098	2,100,606	0.95
Statewide	*5,812,981*	*123,920,748*	*0.99*

$DVMT_{1990+Y} = m(Y) + b$

where

DVMT1990+Y = DVMT (miles/day) in year (1990+Y)

m = slope of line (increase in DVMT per year)

Y = number of years since 1990

b = intercept (best fit DVMT of base year)

R^2 = coefficient of determination for best fit

m and b are in miles/day

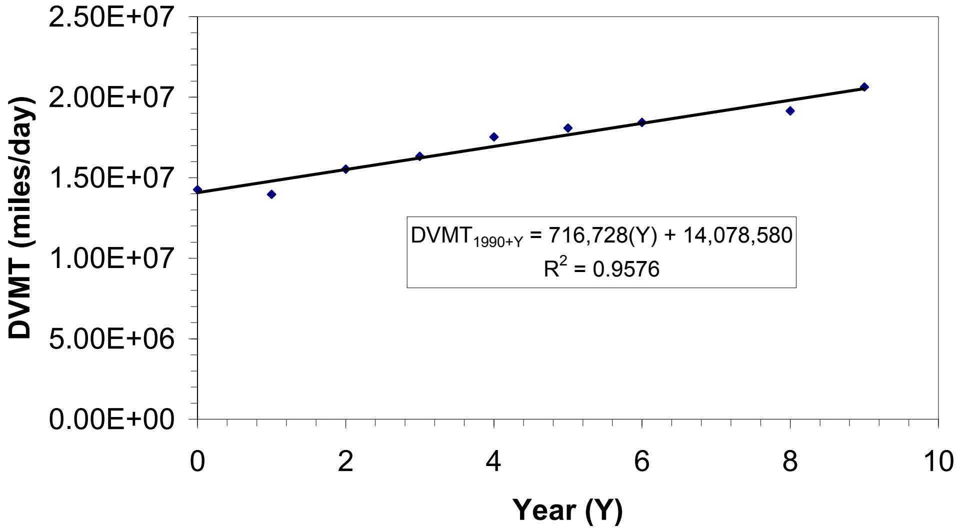

Figure 2-4. Davidson DVMT vs Year (1990-1999)

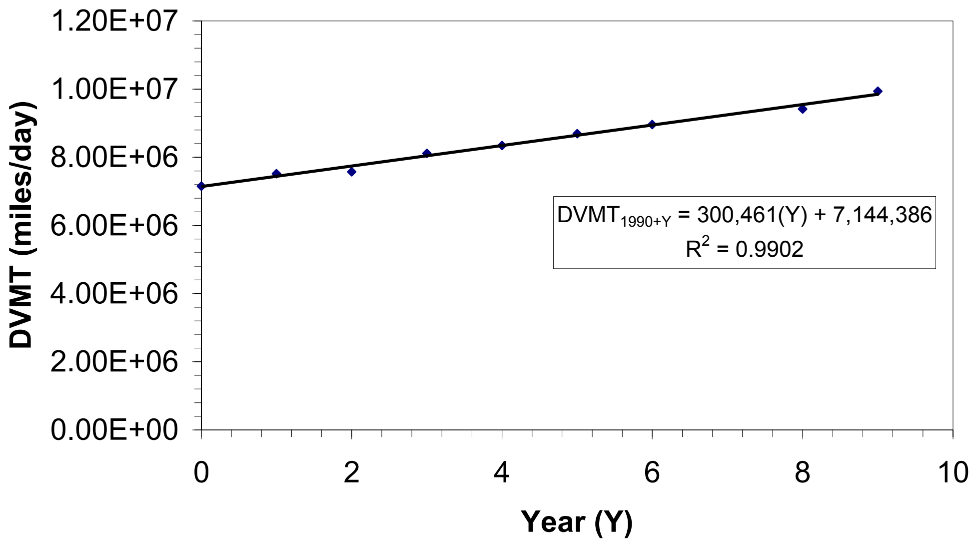

Figure 2-5. Hamilton DVMT vs Year (1990-1999)

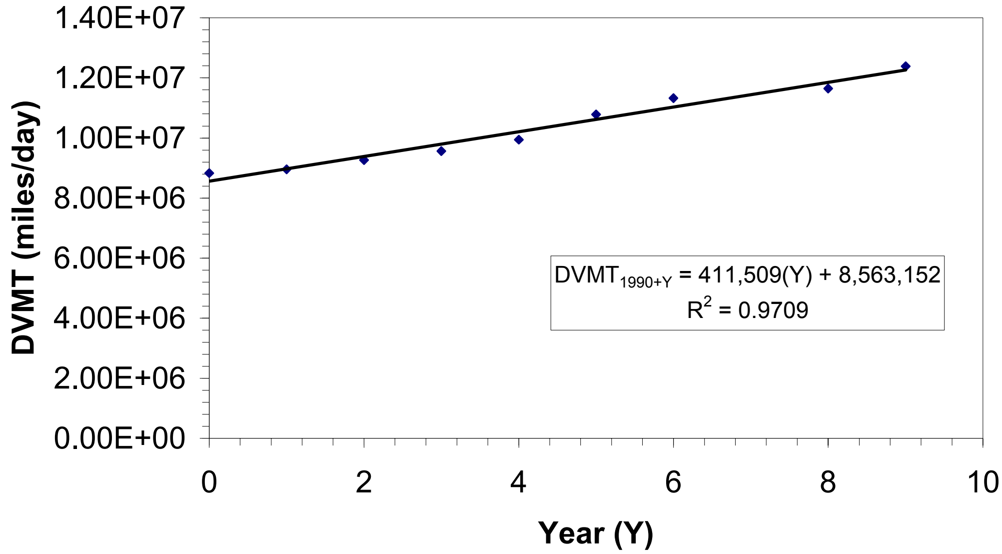

Figure 2-6. Knox DVMT vs Year (1990-1999)

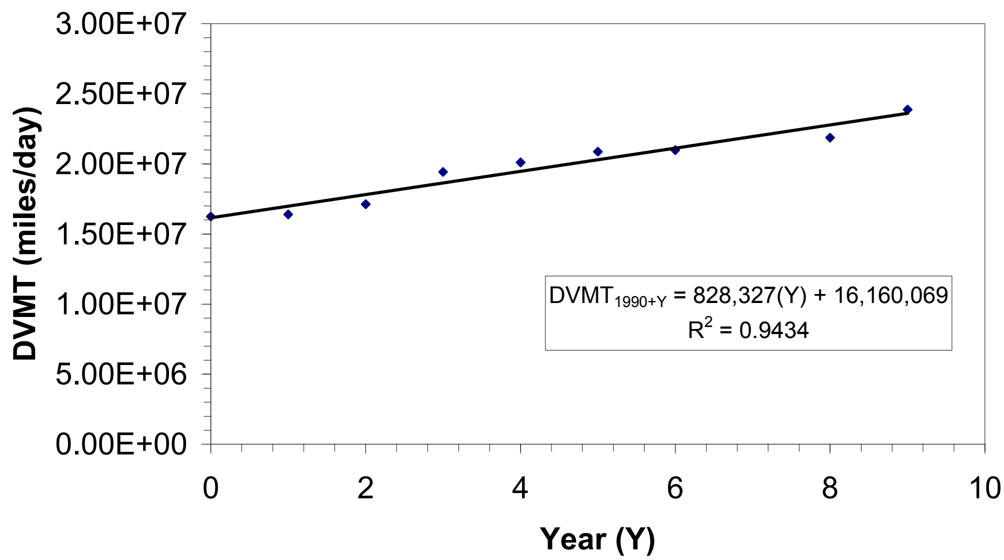

Figure 2-7. Shelby DVMT vs Year (1990-1999)

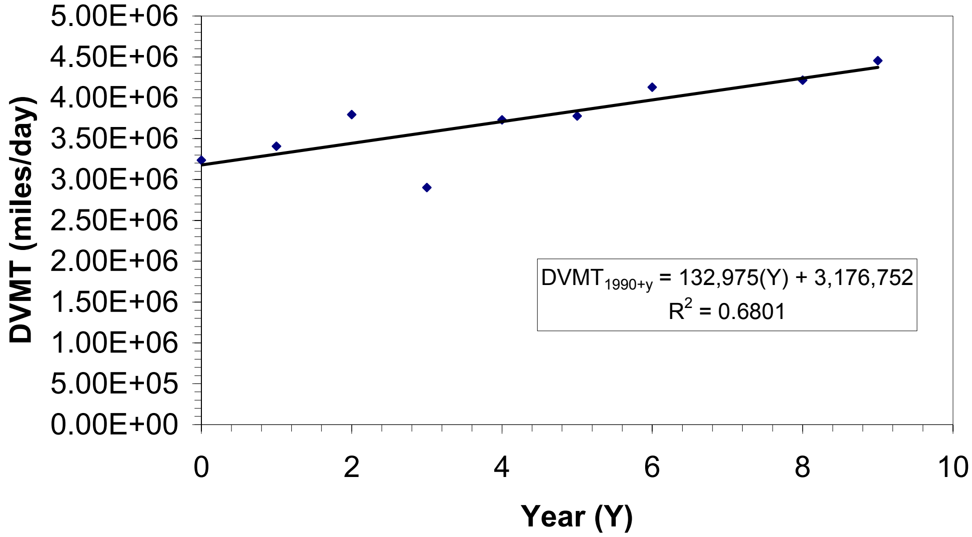

Figure 2-8. Sullivan DVMT vs Year (1990-1999)

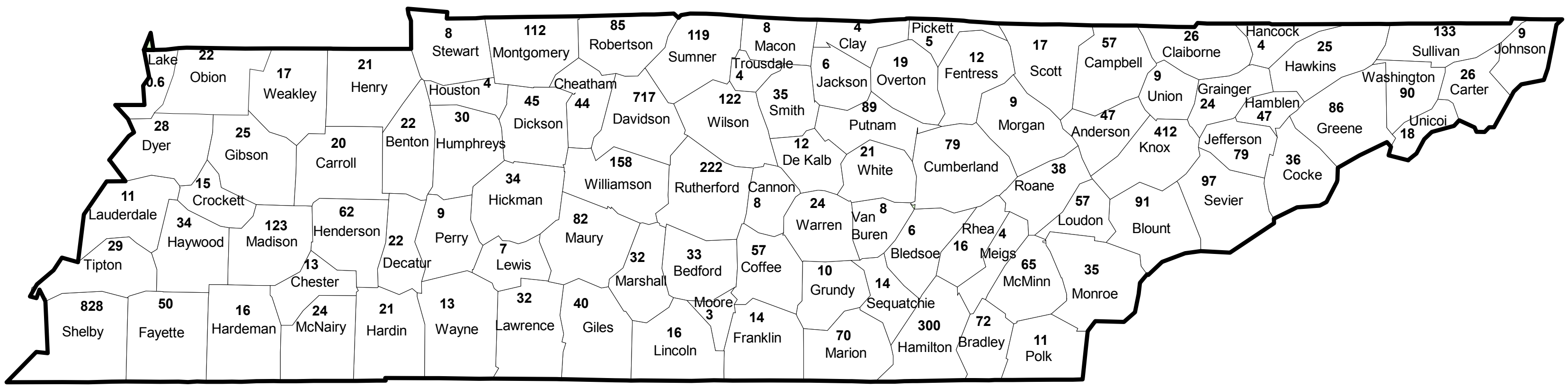

Figure 2-9. Increase in DVMT per year in Thousands of DVMT Based on 1990-1999 DVMT Data

CHAPTER 3

METHODOLOGY

This chapter reviews the methodology for developing the on-road mobile sources emission inventory for the State of Tennessee. Emissions from highway mobile sources were predicted with the latest available mobile source model, MOBILE6 that was released in January 2002. MOBILE6 is an update to the MOBILE5b model that incorporates the effects of the most recent regulations that were promulgated after the release of MOBILE5b, including LEV, Tier2/Sulfur, HDDVNOx and HDDV/Sulfur regulations. MOBILE6 not only includes new regulations but also various updates such as the ability to predict facility-based emission factor emissions for more sophisticated application of results, "real-time" diurnal emission factors, separation of "start" and "running" emissions and other relevant factors (3). This chapter also summarizes the input parameters used in the modeling and calculations of the on-road mobile sources emission projection for years 1999 through 2030.

Most of the required input parameters were set to "default" values built in to the MOBILE6 model. Locality specific input parameters were used in the MOBILE model such as VMT fractions, registration distributions, daily minimum and maximum temperatures, absolute humidity, fuel reid vapor pressure (RVP) and the option of a Inspection and Maintenance (I/M) program. In the following sections, detailed explanations of these input parameters are presented.

3.1. DEVELOPMENT OF REGISTRATION DISTRIBUTION BY AGE FOR TENNESSEE

3.1.1. Introduction

Registration distribution by age is a required input to the MOBILE6 model. It is the fraction of vehicles on the road by vehicle class and age. Although the model allows the use of a national default distribution, inventory guidance requires the use of locality specific distributions where these are available. The MOBILE6 model uses the registration distribution along with annual mileage accumulation rates to evaluate the travel fractions, which in turn are used to weight the emission factors according to the age distribution of the fleet. Hence area specific values may make a difference in the mobile source emission values. For the purpose of this study it is more appropriate to use values developed specifically for the State of Tennessee. Specific registration distribution by age may be developed from different sources such as the registration data, inspection and maintenance data and so on. For this study, area specific registration distributions were developed from the registration data obtained from the Tennessee Department of Safety, Title and Registration Division.

3.1.2. Methodology

Registration data provided by the Tennessee Department of Safety, Title and Registration Division were received on a 3480 cartridge and were in the form of a text file format which was then imported into Microsoft Access®, a database software, to be analyzed further. The data contained information on the county, registration class, make code, model year and body type for vehicles of model year 2001 and earlier. For the purpose of this study, only the following information was used: county, model year, registration class code and the body type. Each county is represented by a two-digit number. Model year is another field in the database that shows the last two digits of the year the vehicle was manufactured. The registration class code gives information on the class under which the vehicle is registered such as a privately owned car, a state owned car or truck, trailers, mobile homes, etc. It also has information on the gross vehicle weight (GVW) for certain classes, which was primarily useful in identifying heavy duty trucks. Lastly the body type code field differentiates the types of vehicles within the main categories of passenger cars, trucks and motorcycles.

For purpose of calculations, the count data for each county were grouped into six area subgroupings (most of which corresponded to a Metropolitan Statistical Area (MSA)):

1. Shelby/Tipton/Fayette Counties (denoted as "*Shelby +*")
2. Davidson/Sumner/Wilson/Williamson/Rutherford Counties (denoted as "*Davidson +*")
3. Hamilton/Marion Counties (denoted as "*Hamilton +*")
4. Knox/Anderson/Loudon/Blount/Sevier/ Union MSA + Jefferson County (denoted as "*Knox +*")
5. Sullivan/Hawkins/Washington/Carter/Unicoi Counties (denoted as "*Sullivan +*")
6. All Other TN Counties (denoted as "*All Other Counties*")

Prior to start of data analysis, any inherent errors in the database such as blank fields (fields without any value/entry) and county number greater than 95 were identified and removed from the database. County number greater than 95 were removed because Tennessee has only 95 counties. The county code information was used to identify and group the data into the different Area Subgroupings. Registration distributions were developed only for two major vehicle categories: light-duty vehicle (LDV, passenger cars less than 8500 lbs GVW), and light-duty trucks (LDT1 and LDT2, less than 6000 lbs GVW; LDT3 and LDT4, 6001-8500 lbs GVW). Body type codes were used to identify the vehicle classification (LDV or LDT). The registration class code was useful in identifying heavy duty trucks. Hence a combination of the body type code and the registration class code was used to classify vehicles as LDV and LDT and to avoid all other vehicle categories from being counted. Since no detailed information was available to evaluate the fractions separately within the light duty truck category (LDT1, LDT2, LDT3 or LDT4), these were grouped together into a single truck category (LDT). Table 3-1 lists the body type codes and registration class codes used to identify and group the two vehicle classifications.

After the vehicles were grouped into the two vehicle categories within each Area Subgroup, the registration fraction was calculated as follows: actual counts of vehicle were collected for each age vehicle starting with two year old vehicles to thirty year old vehicles. The age, for purpose of evaluation, was defined as the number of years that the vehicle had been in service; for example, model year 2000 (for the database of year 2001) was defined as a two year old vehicle. The thirty year old vehicle included all vehicles that were thirty years old and greater. The number of one year old vehicles was assumed to be 75% of the two year old vehicle counts. This is to account for the fact that the

Table 3-1. Body Type and Registration Class Code for Different Vehicle Classifications

LDV		LDT	
Body Type code	**Description**	**Body Type code**	**Description**
4D, 4T, 4H, 4L, 4P	4-Door sedans	PK	Pickup Trucks
2D, 2H, 2L, 2P, 2T	2-Door sedans	VC, VD, VN, VT, VW	Vans
3D, 3P, CP	Coupe	UT	Utility (Blazer and Jimmy)
SW	Station Wagons (as LDVs)	MV	Maxi-Van
CV	Convertible	SV	Sport Vans
SD, SB, SC, 5D, HR, HS, HT, HP, LB	Other Sedans, Coupes and Hatchbacks	JP, LL	Jeep and Carryall
LM, LS	Limousines	3C, 4B, 4C	Extended Cab Trucks
		CB, CC, CG, CH, CL, CM	Custom Pickup
		MH	Camper / Motorhome
		B1, BU	Light Buses
		IC, IE, MY	Incomplete Chassis / Motorized Cutaway
		PN, TB, TL, TM, TN, TR	Miscellaneous Trucks
		CW, CY, DP	Light Cargo and Dump Trucks
		AM	Ambulance
Allowed Registration Class Codes: any of the following - Greater than or equal to 1000 and less than 4000 6000 to 7000, both inclusive			

new cars were assumed to enter into service in the month of October and they have been through only 75% of a year by July 1 (the evaluation month). Using the vehicle counts, the fraction of vehicles in each age category was calculated and plotted. These fractions represent the registration distribution by age. However, the plots do not follow a smooth curve and reflect socio-economical changes that might have occurred over the last thirty years. Since this same data will also be used for estimation of the registration for future years, a best-fit curve was fit to each registration distribution to smooth out the year to year fluctuations. Since the plots depicted curves similar to a bell-shaped or gaussian curve, a gaussian distribution equation was chosen to fit the data set. Sigma Plot® software was used for this purpose.

This method is based on the formula shown below:

$$y = \frac{k}{s}\exp\left(-\frac{1}{2}\left(\frac{x-m}{s}\right)^2\right) \qquad (3.1)$$

where:

y = fraction of vehicles at age x, unitless

k = constant (empirically derived age), years

s = standard deviation of the distribution, years

m = mean of the distribution; represents the age with the highest fraction (where the curve peaks), years

x = age of the vehicle, years

The curve fit function in Sigma Plot® was used to generate best fit values for k, s and m. Since the registration fractions are required to sum up to 1.0, the 'k' value was adjusted until this was achieved. This final 'k' value and the earlier generated 's' and 'm' values, along with coefficient of determination for best fit (R^2), for the various Area Subgroups and vehicle classifications are listed in Table 3-2.

The registration distribution developed for each Area Subgroup for the three major vehicle classifications is tabulated in Tables 3-3, 3-4. The graphs showing the raw fractions and best-fit curves are shown in Appendix A in Figures A1 through A6.

Table 3-2. Gaussian Equation Parameters

LDV:

County	k	m	s	R^2
Shelby +	0.6844	2.5797	8.7591	0.9941
Davidson +	0.6263	3.4574	8.0146	0.9931
Hamilton +	0.5019	7.0683	7.8563	0.9849
Knox +	0.5727	5.3314	8.9611	0.9866
Sullivan +	0.4696	8.6746	7.7825	0.9774
All Other Counties	0.4628	8.5120	7.1341	0.9872

LDT (LDT1, 2, 3 and 4):

County	k	m	s	R^2
Shelby +	0.7979	0.7700	9.9579	0.9806
Davidson +	0.6890	2.4667	8.6599	0.9849
Hamilton +	0.7282	2.2967	11.1308	0.9692
Knox +	0.9410	-1.6265	13.3863	0.9729
Sullivan +	0.6099	5.5319	11.2862	0.9507
All Other Counties	0.5479	7.0948	10.0499	0.9562

Table 3-3. Age Distributions for LDV

Age	Shelby +	Davidson +	Hamilton +	Knox +	Sullivan +	All Other Counties
1	0.0592	0.0641	0.0446	0.0481	0.0355	0.0298
2	0.0780	0.0769	0.0519	0.0596	0.0418	0.0428
3	0.0780	0.0780	0.0559	0.0618	0.0463	0.0481
4	0.0771	0.0780	0.0592	0.0632	0.0504	0.0531
5	0.0752	0.0767	0.0617	0.0639	0.0540	0.0575
6	0.0724	0.0743	0.0633	0.0637	0.0569	0.0610
7	0.0688	0.0709	0.0639	0.0628	0.0590	0.0634
8	0.0645	0.0665	0.0634	0.0611	0.0601	0.0647
9	0.0597	0.0615	0.0620	0.0588	0.0603	0.0647
10	0.0546	0.0560	0.0596	0.0558	0.0595	0.0635
11	0.0492	0.0502	0.0564	0.0523	0.0577	0.0610
12	0.0438	0.0443	0.0525	0.0485	0.0551	0.0576
13	0.0385	0.0385	0.0480	0.0443	0.0517	0.0532
14	0.0334	0.0329	0.0433	0.0400	0.0477	0.0483
15	0.0286	0.0277	0.0384	0.0357	0.0434	0.0429
16	0.0242	0.0230	0.0335	0.0315	0.0387	0.0374
17	0.0202	0.0187	0.0287	0.0274	0.0340	0.0320
18	0.0166	0.0151	0.0243	0.0235	0.0294	0.0268
19	0.0135	0.0119	0.0202	0.0200	0.0250	0.0220
20	0.0108	0.0093	0.0165	0.0167	0.0209	0.0177
21	0.0086	0.0071	0.0133	0.0139	0.0172	0.0140
22	0.0067	0.0054	0.0105	0.0113	0.0139	0.0109
23	0.0052	0.0040	0.0082	0.0091	0.0111	0.0082
24	0.0039	0.0029	0.0063	0.0073	0.0087	0.0061
25	0.0030	0.0021	0.0047	0.0057	0.0067	0.0045
26	0.0022	0.0015	0.0035	0.0045	0.0051	0.0032
27	0.0016	0.0010	0.0026	0.0034	0.0038	0.0023
28	0.0012	0.0007	0.0018	0.0026	0.0028	0.0016
29	0.0008	0.0005	0.0013	0.0020	0.0020	0.0010
30	0.0006	0.0003	0.0009	0.0014	0.0014	0.0007
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 3-4. Age Distributions for LDT (LDT1, 2, 3 and 4)

Age	Shelby +	Davidson +	Hamilton +	Knox +	Sullivan +	All Other Counties
1	0.0613	0.0607	0.0456	0.0577	0.0427	0.0369
2	0.0795	0.0794	0.0654	0.0678	0.0515	0.0479
3	0.0781	0.0794	0.0653	0.0662	0.0527	0.0502
4	0.0760	0.0783	0.0647	0.0644	0.0535	0.0520
5	0.0732	0.0762	0.0635	0.0622	0.0540	0.0533
6	0.0698	0.0732	0.0619	0.0598	0.0540	0.0542
7	0.0659	0.0694	0.0598	0.0571	0.0536	0.0545
8	0.0616	0.0649	0.0574	0.0543	0.0528	0.0543
9	0.0569	0.0599	0.0546	0.0513	0.0515	0.0535
10	0.0521	0.0545	0.0515	0.0482	0.0500	0.0523
11	0.0473	0.0490	0.0482	0.0451	0.0481	0.0505
12	0.0424	0.0434	0.0447	0.0419	0.0459	0.0484
13	0.0377	0.0380	0.0412	0.0387	0.0434	0.0459
14	0.0331	0.0328	0.0376	0.0356	0.0408	0.0431
15	0.0289	0.0279	0.0341	0.0325	0.0380	0.0400
16	0.0249	0.0235	0.0307	0.0295	0.0351	0.0368
17	0.0212	0.0195	0.0273	0.0267	0.0322	0.0335
18	0.0179	0.0159	0.0242	0.0240	0.0294	0.0303
19	0.0150	0.0129	0.0212	0.0214	0.0265	0.0270
20	0.0124	0.0102	0.0185	0.0191	0.0238	0.0239
21	0.0102	0.0081	0.0159	0.0168	0.0211	0.0209
22	0.0083	0.0063	0.0137	0.0148	0.0186	0.0181
23	0.0066	0.0048	0.0116	0.0129	0.0163	0.0156
24	0.0053	0.0036	0.0098	0.0112	0.0142	0.0132
25	0.0042	0.0027	0.0082	0.0097	0.0122	0.0111
26	0.0032	0.0020	0.0068	0.0084	0.0104	0.0093
27	0.0025	0.0014	0.0056	0.0071	0.0089	0.0077
28	0.0019	0.0010	0.0045	0.0061	0.0074	0.0063
29	0.0014	0.0007	0.0037	0.0051	0.0062	0.0051
30	0.0011	0.0005	0.0030	0.0043	0.0052	0.0041
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

3.1.3. Use of Developed Registration Fractions in MOBILE6 Model

The developed registration fractions were used for mobile source emission calculations using the MOBILE6 model for areas within Tennessee. For those Area Subgroups listed above, the corresponding calculated fractions were used for the LDV, and the LDT (LDT1, 2, 3 and 4) vehicle categories; national default values were used for the remaining 11 vehicle categories. For the case of "All Other Counties" the following approach was used: when the total interstate (freeway + interstate) DVMT exceeded 50% of the total DVMT for a particular county, national default values were used instead of the generated fractions. This is based on the assumption that, in a rural county that has a major interstate flowing through it, the majority of vehicles on the interstate may not necessarily be those that are registered in that county and are most likely a part of the "through" traffic. Hence, the registration data for that county would not provide information that would be representative of the actual vehicle mix that is on the road. For counties that had interstate DVMT that is less than 50% of the total DVMT for the county, the "All Other Counties" calculated fractions were used for the LDV and LDT categories; National default values were used for the rest.

3.2. DEVELOPMENT OF VMT MIX FRACTIONS FROM THE TENNESSEE VEHICLE REGISTRATION DATA

3.2.1. Introduction

The VMT mix represents the fraction of vehicle miles traveled (VMT) that is accumulated by each vehicle category on the highway. For example, if the VMT mix fraction for Light Duty Vehicles (LDV) is 60%, then it implies that 60% of the total

VMT is accumulated by LDV on the highway. It was realized in this study that the VMT mix data provided by TDOT was not suitable for mobile source emission modeling due to the discrepancy in the way LDV and LDT were defined in the data collection process by TDOT versus the way that the U.S.EPA defines these categories (i.e. all minivans, SUVs etc., are LDT based on U.S.EPA emission standards). TDOT vehicle mix data were obtained from actual vehicle counts on the highway, which were performed by automated counters and were allocated to LDV or LDT category based on the axle distance of the vehicle. This approach, however, does not conform to the EPA's MOBILE6 definition of LDV and LDT. A LDT may be allocated to LDV category if the axle distance was comparable to that of a car. Thus, while the data generated by the TDOT procedure for the LDV and LDT category is suitable for some uses, it is not suitable for use in allocating emissions by vehicle type for LDV and LDT categories. However, the TDOT-generated data were assumed to be correct for the heavy duty vehicle categories. In addition, visual counts performed by researchers at UTK on the interstates and highways around the Knoxville area, revealed that the information on VMT mix for LDV and LDT categories were substantially different from that provided by TDOT. It was thus necessary to come up with an approach to develop the VMT mix fractions for the LDV and LDT categories. The following section summarizes the procedure that was followed in developing these fractions based on the State's vehicle registration data.

3.2.2. Methodology

The VMT mix information originally provided by TDOT had VMT mix fractions for the following vehicle categories (as per definition of MOBILE5b): LDGV, LDGT1, LDGT2, HDGV, LDDV, LDDT, HDDV and MC. In the following discussion, the vehicle classifications referred to are according to Mobile5b definition. Of the above eight categories, new VMT mix fractions were developed only for LDGV, LDGT1 and LDGT2 categories. The fractions for the remaining categories were unchanged and were assumed to remain constant over time (2000 to 2030). VMT mix fractions for the different vehicle categories were developed from the vehicle registration data. Analysis of the registration data gives information on the fraction of LDV, LDT etc., that were registered in the State of TN. These fractions may or may not represent the VMT fraction of each of those vehicle categories on the road depending on the vehicle miles traveled by each of those categories. For example, even if the number of registered trucks is less than that for cars, their VMT fractions need not necessarily be less than that of the cars, because of the fact that they are driven more miles than cars. As explained in section 3.1, vehicle registration information was analyzed for LDV and LDT vehicle classifications only. Thus, the readily available data on the *number* of registered LDV and LDT vehicles had to be expressed on a different basis in terms of *vehicle miles driven* by LDGV, LDGT1 and LDGT2 vehicle classifications. This was accomplished by multiplying the vehicle counts (number of registered vehicles) in each category by the miles per year driven by the respective vehicle category. The resulting values, which are the total miles driven by each vehicle category, were then expressed as a fraction of the total miles driven by all vehicle categories summed together, to obtain the VMT Mix fraction. It must be noted that while the VMT Mix fractions were being developed for LDGV, LDGT1 and LDGT2 categories (two truck classifications), available counts were for Light duty vehicles (LDV) and Light duty Trucks (LDT – all truck sub-classifications combined) each of which include both gasoline and diesel. Although the vehicle counts obtained for LDV and LDT include diesel vehicles in addition to gasoline vehicles, it was assumed that the percentage of diesel vehicles small and would create a negligible change in the relative fractions of LDGV and LDGT. Hence, the LDV and LDT vehicle counts (which include diesel vehicles) were assumed to be representative of LDGV and LDGT counts. Also, it was necessary to find VMT fractions for the two light duty truck classifications, LDGT1 and LDGT2, from the vehicle counts for the whole light duty truck category (LDT). This was done using the default ratio of LDGT1 to LDGT2 available in the MOBILE6 model. In order to proceed with the calculation, the following parameters were needed: miles per year driven by LDGV, miles per year driven by LDGT and the default ratio of LDGT1 to LDGT2 in MOBILE6. The vehicle miles driven by any vehicle in each year is represented by the annual mileage accumulation rate (AMAR) values in the MOBILE6 model. In the MOBILE6 model, AMARs are available for LDGV, LDGT1 and LDGT2 by age. Since the number of vehicles in each vehicle classification is a total count of all age vehicles, an average value of AMAR (weighted by age mix) was determined for each of the vehicle classification (LDGV, LDGT1 and LDGT2) as per the equation below:

$$Average\ AMAR = \sum_i \left[\left(fraction\ of\ registered\ vehicles \right)_i \times \left(AMAR \right)_i \right]$$

where

i = age of vehicle

(fraction of registered vehicles)$_i$ = fraction of vehicles in each age based on the TN vehicle registration data

$(AMAR)_i =$ EPA default MOBILE6 annual mileage accumulation rate for each vehicle age.

Also, since there was a value for both LDGT1 and LDGT2, a single value for the combined truck category (LDT) needed to be determined. This was done by multiplying the miles/year value (AMAR value) for each vehicle classification (LDGT1 and LDGT2) by the respective EPA default MOBILE6 vehicle count fraction and summing them up to yield a single value. The procedure for calculating the EPA default vehicle count fraction was essentially tracing back through the VMT mix fraction calculation. The following equations guide through the calculation process:

$$fraction\ x_1 = \frac{Default\ VMT\ Mix\ fraction\ of\ LDGT1\ (as\ \%\ of\ light\ duty\ category)}{Default\ AMAR\ (weighted\ by\ age\ mix)\ for\ LDGT1}$$

$$fraction\ x_2 = \frac{Default\ VMT\ Mix\ fraction\ of\ LDGT2\ (as\ \%\ of\ light\ duty\ category)}{Default\ AMAR\ (weighted\ by\ age\ mix)\ for\ LDGT2}$$

where x_1 and x_2 are fractions proportional to the default MOBILE6 vehicle counts of LDGT1 and LDGT2 respectively. The ratios of x_1 to $(x_1 + x_2)$ and x_2 to $(x_1 + x_2)$ yield the EPA default MOBILE6 vehicle count fractions of LDGT1 and LDGT2, respectively. Using these fractions, a single AMAR value for LDGT was determined as explained earlier.

Using the AMAR values for LDGV available in the MOBILE6 model, and the calculated AMAR value for LDGT, the total miles driven per year by LDGV and LDGT were determined for each of Area Subgroups by multiplying the locality specific LDV and LDT vehicle counts by the EPA MOBILE6 default AMAR values. Each of these individual values, when expressed as a fraction of the total miles driven by both LDGV and LDGT, give the VMT mix fraction for the respective vehicle category as a fraction of the light duty category. LDGT was proportioned into LDGT1 and LDGT2 based on the national default mix of 74.4% and 25.6%, respectively.

Thus, VMT mix values for LDGV, LDGT1 and LDGT2 were generated for the year 2000. These were then linearly extrapolated to the 2008 default VMT Mix fractions (expressed as a percent of the light duty category) assumed by the MOBILE6 model. The VMT mix fractions for years after 2008 were assumed to be the same as the MOBILE6 default fractions. The time frame 2008 was chosen since EPA assumed that the ratio of LDV to LDT vehicle sales would stabilize nationwide at a 40:60 ratio by the year 2008. For the vehicle categories other than LDGV, LDGT1 and LDGT2, it was assumed that the VMT fractions provided by TDOT were correct and that they would remain unchanged for future years.

The above approach yields a table of VMT fractions (expressed as a percent of the light duty category) for years 2000 through 2030. These VMT fractions were then normalized over the whole fleet in a manner such that the total percentage of (LDGV + LDGT1 + LDGT2) was equal to 100 percent minus the percentage of (HDGV + LDDV + LDDT + HDDV + MC). For example, consider the following as part of the original VMT Mix values provided by TDOT:

LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	Total
0.664	0.142	0.034	0.034	0.007	0.002	0.115	0.002	1.000

In this case, the sum of the VMT fractions for the light duty category (LDGV+LDGT1+LDGT2) is 0.84. That is, 84% of the VMT of the whole fleet is accumulated by the light duty category. Since the values of LDGV, LDGT1 and LDGT2 were determined by the approach explained earlier in this document, they have to be substituted for the values in the above table. If, for example, say the VMT mix (as a percent of the light duty category) calculation for a particular case turns out to be

LDGV = 0.5223, LDGT1 = 0.2888 and LDGT2 = 0.1889

then, the normalized values would be

LDGV = 52.23% of 0.84 = 0.4387

LDGT1 = 28.88% of 0.84 = 0.2426

LDGT2 = 18.89% of 0.84 = 0.1587

Thus the new table would contain the following values as VMT fractions for the whole fleet:

LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	Total
0.4387	0.2426	0.1587	0.034	0.007	0.002	0.115	0.002	1.000

This approach was followed for the each of the Area Subgroups for which the registration distribution was developed.

Shift from MOBILE5b vehicle classification to MOBILE6 classification

The VMT Mix fraction input to the MOBILE6 model requires 16 vehicle classes. Thus, adjustments to the MOBILE5b-based VMT Mix fractions were necessary. Table 3-5 lists the approach that was used to convert from VMT Mix fractions based on the MOBILE5b definition to VMT Mix fractions based on the MOBILE6 definition. The LDV category included gasoline and diesel cars. The percentages that were used to apportion LDGT1,

Table 3-5. Conversion from MOBILE5b based VMT Mix to MOBILE6 based VMT Mix

MOBILE6 based vehicle definition	**Calculation/Adjustment made to MOBILE5b based fraction**
LDV	LDGV + LDDV
LDT1	0.231(LDGT1 + LDDT)
LDT2	0.769(LDGT1 + LDDT)
LDT3	0.692(LDGT2)
LDT4	0.308(LDGT2)
HDV2B	HDGV
HDV3	0
HDV4	0
HDV5	0
HDV6	0
HDV7	0
HDV8A	0.231(HDDV)
HDV8B	0.769(HDDV)
HDBS	0
HDBT	0
MC	MC

LDDT, LDGT2 into the respective MOBILE6 truck category were based on the default ratios in MOBILE6. The heavy duty categories of MOBILE5b (HDGV and HDDV) were assigned to eight classes of heavy duty vehicles as follows. It was assumed that the HDV2B category of MOBILE6, consisted of mostly gasoline vehicles. Hence all the HDGV VMT Mix of MOBILE5b was assigned to the HDV2B class of MOBILE6. Similarly, the HDV8 class of MOBILE6 consisted of primarily diesel vehicles. Hence the HDDV VMT Mix of MOBILE5b was assigned to HDV8A and HDV8B in the ratio of 0.231 and 0.769. The ratios were based on default ratios in the MOBILE6 model. The VMT Mix fraction for the other classes of the heavy duty category were set to zero. The VMT Mix for the diesel school bus and commercial diesel bus were also set to zero.

3.2.3. Use of Developed VMT Mix in MOBILE6 model

Locality specific VMT mix values were provided by TDOT for the following Counties: Knox, Davidson, Rutherford, Sumner, Williamson, Wilson, Hamilton and Shelby. As mentioned earlier, these fractions were used unchanged for vehicle classifications other than LDGV, LDGT1 and LDGT2 and calculated values were used for LDGV, LDGT1 and LDGT2. For the "All Other Counties" subgroup and the "Sullivan +" subgroup, VMT mix fractions for the vehicle classifications other than LDGV, LDGT1 and LDGT2 were assumed to be the arithmetic average of the VMT mix fractions of the available eight Counties. The VMT mix fractions for LDGV, LDGT1 and LDGT2 for these two subgroups were determined as per the procedure explained in section 3.2.2. The same VMT mix values were used for all the Counties within a subgroup. The developed VMT Mixes are shown in Appendix B.1 (Tables B.1-1 through B.1-10).

3.3. DEVELOPMENT OF THE ON-ROAD MOBILE SOURCES EMISSION INVENTORY FOR THE STATE OF TENNESSEE

3.3.1. Emissions Calculation Methodology

Emission factors generated from the MOBILE6 model were in terms of grams/mile of travel. Therefore, when the factor is multiplied by the daily vehicle miles traveled (DVMT) it gives the emissions in units of mass/day (e.g. tons per day). The baseline year calculations were done for 1999, the latest year for which Tennessee DVMT data by county for each functional roadway classifications were available at the time of this study. The baseline DVMT were then projected for future year emission calculations as explained in Chapter 2 (i.e., a linear extrapolation of the straight line fit to the 1990-1999 DVMT data by county in Tennessee). It was assumed in the calculations that the DVMT increase per year for each county would remain constant in the future and equal to the value determined for the period 1990 through 1999 for that county, per TDOT recommendation.

For each subgroup, the MOBILE6 runs were done separately for RURAL and URBAN roadway classifications. Also for counties which had an existing inspection and maintenance (I/M) program, it was also necessary to run the MOBILE6 model "with" and "without I/M" program in order to address the fact that not all vehicles which drive through a county were subject to the I/M requirement. Emission calculations for counties with I/M programs were calculated according to the following equation:

Composite Emissions in tons/day =

$$\{[(EF \text{ with } I/M) * (f1)] + [(EF \text{ without } I/M) * (f2)]\} * DVMT * 1.102\text{x}10^{-6} / SAF \qquad (3.2)$$

where

EF = composite emission factor from MOBILE runs with/without I/M, g/mile

f1 = fraction of vehicles that have been subject to I/M that drive through the county

f2 = fraction of vehicles that have not been subject to I/M that drive through the county

SAF = seasonal adjustment factor for DVMT

$1.102\text{x}10^{-6}$ = conversion factor to convert grams to tons.

For those counties that are not subjected to the I/M program, Equation 3.3 was used for the emission calculation, as follows:

$$\text{Composite Emissions in tons/day} = (EF \text{ without } I/M) * DVMT * 1.102\text{x}10^{-6} / SAF \qquad (3.3)$$

where

EF = emission factor from MOBILE runs without I/M, g/mile

SAF = seasonal adjustment factor for DVMT

$1.102\text{x}10^{-6}$ = conversion factor to convert grams to tons.

The composite emission factor in the equation is the sum of emissions by roadway type from the MOBILE runs. These emission factors from the MOBILE runs are weighted by vehicle type and VMT mix for each roadway classification and the emission factors were reported by roadway classification for each particular analysis year.

The SAF is a factor that is used to adjust the average daily vehicle miles traveled to that of a typical average summer day. The values were obtained from TDOT and were developed from the 1996 monthly variation factors that describe the changes in the VMT by day of the week for every month. The SAF factor used in this study was taken to be the average of the monthly variation factors for each of the seven days of the week for the three months: June, July and August. This was done so that the DVMT would be representative of a typical summer (weekend and weekdays combined) day. Table 3-6 shows a tabulation of the SAF values used in Equation 3.2 and 3.3.

Table 3-6. Seasonal Adjustment Factors (SAF)

Roadway Classification	**SAF**
Rural Freeway	0.912
All Other Rural Roadway Types	0.973
All Urban Roadway Types	0.985

MOBILE6 provides for the calculation of emission factors for interstate, ramp, arterial, and local roadway classification. However, DVMT for each county in Tennessee (as provided by TDOT) does not include values for the "ramp" classification at the present time but includes interstate (interstate + freeway), principal and minor arterial, collector and local classification. To address this issue, it was assumed that the DVMT on "Urban Ramps" was 8% of the total DVMT allocated to the Urban Interstate/freeway category in the TDOT DVMT data. This was based on information provided in a recent

EPA report (12). Consequently, the DVMT that was allocated to the "Urban Interstate/Freeway" was 92% of the total DVMT on Urban Interstate/Freeways and DVMT for "Urban Ramps" was 8%. For the case of "Rural Ramp," it was assumed that the DVMT on the ramps was insignificant when compared to the DVMT on the interstates on the basis that most of the rural interstate VMT is "through" traffic not using ramps, ramp lengths are very small compared to interstate length and ramps were less frequent and further apart than in urban areas. Therefore, DVMT on "Rural Ramp" was set to zero. The DVMT on the "Arterial" classification was taken to be the sum of the DVMT on the "Principal Arterial", "Minor Arterial" and "Collector" roadway types, since MOBILE6 only contains one "arterial" roadway classification.

3.3.2. MOBILE6 Input Parameters for Area Subgroups

MOBILE6 runs were done for all the area subgroups as mentioned in the previous section. For Shelby County, Knox County and the Davidson+ area subgroup, most of the input parameters were based on the information available from the respective MPO Long Range Transportation Plans. Locality specific temperature, absolute humidity, and registration distribution data were generated. Daily minimum and maximum temperature is a required input to the MOBILE model. These temperatures were determined by selecting the average of the maximums and the average of the minimums on those days that recorded the 10 highest 8-hr average ozone concentrations for the period of 1998-2000. This was done separately for East, Middle and West Tennessee. The absolute humidity (in terms of grains per pound) was calculated according to the following equations:

$$\text{Absolute Humidity} = \left(\frac{\text{SH} \times 15.43}{2.205}\right) \tag{3.4}$$

$$\text{SH} = \left(\frac{(0.62197 \times \text{VPa})}{\text{Pm} - (0.37803 \times \text{VPa})}\right) \times 1000 \tag{3.5}$$

$$\text{VPa} = 6.11 \times 10 \times \left(\frac{(7.5 \times \text{Tdc}}{(237.7 + \text{Tdc})}\right) \tag{3.6}$$

where

SH = Daily Average Specific Humidity, g/kg

0.62197, 0.37803, 6.11, 7.5, 237.7 = constants, unitless

Pm = Atmospheric Pressure, milibars

VPa = Daily Average Actual Vapor Pressure, milibars

Tdc = Daily Average Dewpoint Temperature, Celsius

Absolute Humidity = Daily Average Absolute Humidity, grains/lb

15.43 = conversion factor to convert grams to grains

2.205 = conversion factor to convert kilograms to pounds

Absolute humidity was calculated for the following combinations: Minimum temperature and maximum relative humidity; and maximum temperature and minimum relative humidity. The minimum of these two values was found for each of the days selected. The average of those minimums was used for modeling. Although the EPA technical guidance (13) suggests the use of either the lowest of the minimum values or the value of minimum absolute humidity that would not exceed 100% saturation, it was felt that, for purposes of modeling, the average of the minimums was representative compared to either of the extremes. The results of the temperatures and absolute humidity analyses for East, Middle and West Tennessee are listed in Table 3-7a through 3-7c respectively for the period of 1998-2000. For the purpose of this study, the counties that were classified into East, Middle, and West Tennessee are illustrated in Figure 3-1 and a list of the counties included in each area is tabulated in Table C1.

3.3.3. Specific Input Parameters For MOBILE6 Runs

The input file to the MOBILE6 model consists of three sections: the Header Section, the Run Section, and the Scenario Section. The Header Section controls the overall input, output, and execution of the program. The Run Section defines parameter values that localize or customize the runs. Details and calculation of emission factors for individual scenarios are included in the Scenario Section.

3.3.3.1. Shelby + Subgroup

For the Shelby+ subgroup, two runs were done separately for Shelby County and Tipton/Fayette County. This was because Shelby County had an ongoing I/M program and assumed future anti-tampering program, while the other two counties did not. Moreover, there were slight changes in parameters such as the fuel RVP etc. Most of the input parameters for Shelby County were developed based on the information available from the Memphis MPO Long Range Transportation Plan. The input parameters are tabulated separately for Shelby County and for Tipton and Fayette Counties in Tables D2 and D3, respectively.

Table 3-7. Highest 8-hr Maximum Ozone Levels
a. East Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	123	Aug-25-98	Knox21	91	65	82
2	122	Jun-01-00	Knox102	86	63	84
3	121	Jul-23-99	Blount102	93	72	116
4	118	Aug-06-98	Knox21	90	65	90
5	117	Jun-26-98	Knox21	94	72	113
6	116	Sep-12-98	Blount101	90	55	59
7	116	Jul-03-99	Jefferson	90	69	103
8	115	Aug-28-98	Knox21	94	67	83
9	115	Jul-04-99	Jefferson	91	71	108
10	115	Jun-09-00	Sullivan3	85	58	73
Average				**90**	**66**	**91**

b. Middle Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	120	Aug-17-99	Wilson	97	67	71
2	114	Sep-06-99	Lawrence	92	66	70
3	111	Aug-05-98	Sumner7	89	68	92
4	111	May-18-98	Williams	87	53	53
5	110	Aug-04-98	Sumner7	87	69	86
6	110	Sep-04-99	Sumner7	96	70	79
7	110	Sep-05-99	Sumner7	99	65	56
8	108	Jun-25-98	Sumner7	96	74	111
9	108	Sep-03-99	Lawrence	96	62	56
10	108	Jun-01-00	Sumner7	88	64	79
Average				**93**	**66**	**75**

c. West Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	124	May-18-98	Shelby21	91	64	62
2	110	Jul-09-99	Shelby21	92	76	126
3	109	Aug-23-98	Shelby100	93	69	87
4	108	Aug-28-98	Shelby100	97	68	94
5	107	Jul-26-00	Shelby21	95	70	70
6	107	Sep-06-98	Shelby100	97	74	91
7	107	Sep-04-99	Shelby21	96	70	105
8	106	Sep-19-99	Shelby21	92	63	48
9	104	May-21-98	Shelby100	92	72	93
10	104	May-19-98	Haywood1	92	70	79
10	104	Aug-22-00	Shelby21	100	77	106
10	104	Aug-19-99	Shelby21	97	73	90
Average				**95**	**71**	**88**

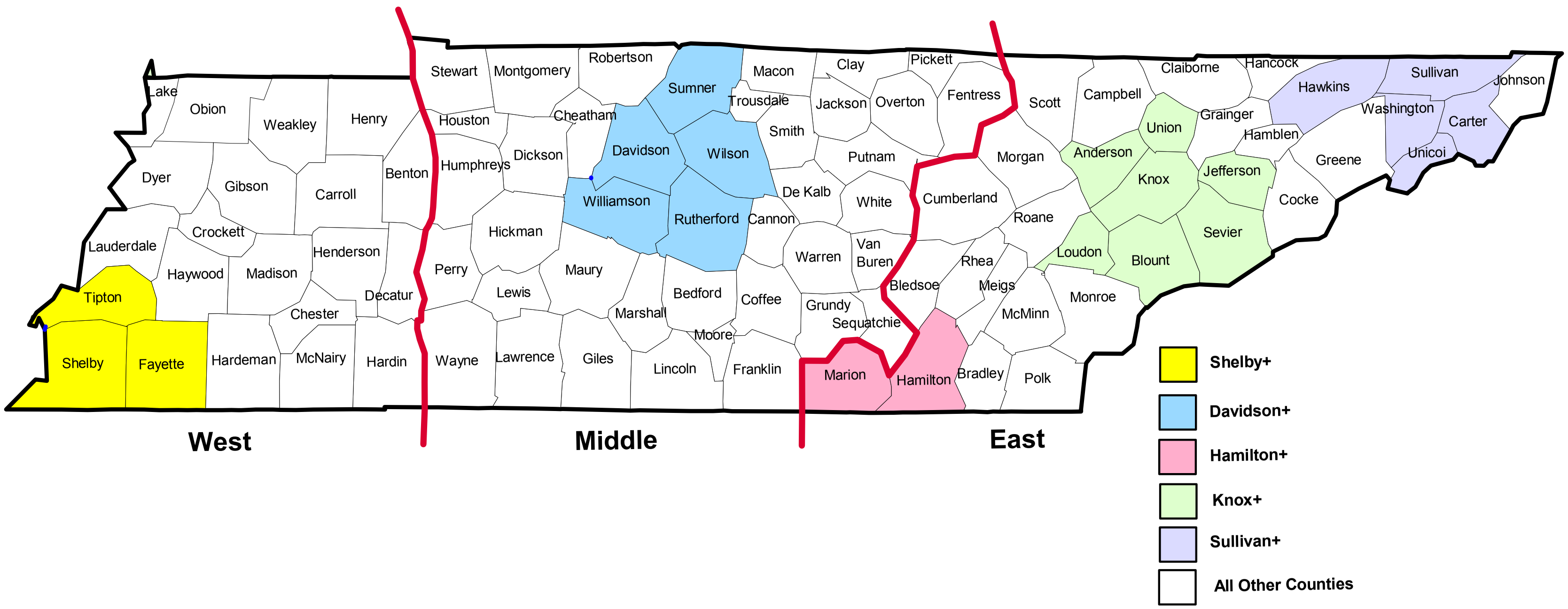

Figure 3-1. Map of the Area Subgroups and the Counties Classified as East, Middle and West Tennessee

3.3.3.1a. Shelby County

Header Section: The input commands and their respective input parameters are shown in Table D1 of the appendix. The output for the runs was specified to be in database format.

Run Section: The Run Section containing the input commands and parameters are shown in Tables D2a through D2f of the appendix. Refueling emissions were not considered in the calculations. West Tennessee average minimum absolute humidity and temperatures (average minimum and average maximum) were used in these runs. Speed values were developed for different roadway classifications based on data obtained from MPO modeling and speed measurement studies. The speeds were developed for Freeway (interstate and freeway) and Arterials (principal arterials, minor arterials and collectors). The speed values used in this study are shown in Table 3-8 in bold under the column "VMT Weighted Mean Speed" for both rural and urban roadway classifications. For Ramps and Local classifications, national default speeds were used. A specific Shelby County VMT mix was used in the modeling listed under the command "VMT FRACTIONS". In this study, it was assumed that the vehicle speed does not change in future years and remains the same throughout the modeling period. Locality specific registration distribution by age (Shelby+) was used and the data were developed as described earlier in the chapter. In accordance with the Memphis MPO Long Range Transportation Plan, it was assumed that an ongoing I/M program exists in the City of Memphis only, and would remain unchanged until the start year of 2020. It was also assumed that a more stringent county-wide I/M program would become effective in the analysis year 2020 and later.

Table 3-8. Summary of Tennessee Highway Speed vs. MOBILE6 Defaults

Roadway Type	TDOT 1999 VMT	Percent of Total (%)	Arterial and Collector Fraction	Average Speed† (mph)	VMT Weighted Mean Speed (mph)	MOBILE6 Default Speeds (mph)	Consolidated Roadway Types
<u>Rural</u>:							
Interstate	25020954	30.6		63.8	**63.8**	36.5	**Freeway**
Principal Arterial	14983302	18.3	0.298*	44.9			
Minor Arterial	15887047	19.5	0.316*	41.9	**40.8****	31.2	**Arterial**
Collector	19412282	23.8	0.386*	37.3			
Local	6353000	7.8		27.2	27.2	**12.9**	**Local**
Ramps				N/A	N/A	N/A***	**Ramps**
<u>Urban</u>:							
Interstate	28244045	29.1		54.9	**54.9**	36.5	**Freeway**
Principal Arterial	28181182	29.1	0.505*	33.5			
Minor Arterial	20810701	21.5	0.373*	33.2	**32.8**	31.2	**Arterial**
Collector	6849480	7.1	0.123*	29.3			
Local	12894000	13.3		20.9	20.9	**12.9**	**Local**
Ramps				N/A	N/A	**34.6**	**Ramps**

N/A – Not Applicable
*Fraction based on the sum of Principal, Minor Arterials and Collectors
**VMT Weighted Mean Speed = (0.298 x 44.9) + (0.316 x 41.9) + (0.386 x 37.3) = 40.8 mph
***Not Applicable since ramp VMT on rural interstates was assumed to be negligible compared to interstate VMT
†See Appendix B.2 for detailed discussion of average speed derivations.

The traditional exhaust I/M program (IDLE) was used to cover pre-1996 model year vehicles and the On-Board Diagnostic (OBD) exhaust I/M program was used for 1996 and newer model year vehicles. In addition, the Evaporative OBD and Gas Cap (GC) evaporative I/M program was assumed to be in place, beginning in 2002, and was applied for 1996 and newer model year vehicles. The earliest model year that was subjected to I/M program was determined based on a 25-year window. For example, if one were to model for analysis year 1999 then the earliest model year subjected to I/M program would be model year 1974. Hence, the "Exemption Age" input parameter was set to 25. Also, an Anti-Tampering Program (ATP) was assumed to be effective starting with year 2019. Other parameters for I/M and ATP program were also chosen based on the Memphis MPO Long Range Transportation Plan. The input parameters for I/M Programs (I/M Programs 1, 2 3,4 and5) are shown in Table D2b through D2f respectively. The I/M program had to be split up into multiple programs (I/M Program 1 and I/M Program 2 and so on) due to reasons such as to avoid double counting of I/M effects, to avoid conflicting dates in I/M start years for Light duty vehicles and heavy duty gasoline vehicles etc. Anti-tampering Program (ATP) input parameters are shown in the run section input parameter tables (Table D2).

Although the last analysis year modeled in the Long Range Plan was 2020, it was assumed that the parameters shown for the analysis year 2020 in the Long Range Plan would remain valid and unchanged for analysis years 2025 and 2030. The Reid vapor pressure used in the model (RVP 7.8) was the same as was used by the Memphis MPO and corresponded to that recommended by ASTM guidance.

Scenario Section: The input commands and their respective input parameters are shown in Table D9 of the appendix. The scenario record was used as a label for individual scenario results. The Calendar Year input parameter was used to identify the calendar year for which emission factors were to be calculated. The runs were modeled for calendar years 1999 through 2010, and for the years 2015, 2020, 2025, and 2030. The Evaluation Month for all the runs was set to July 1st to be representative of the ozone season.

Emission Calculations: Once the input files were prepared, the MOBILE6 model was run with inclusion of all regulations. In order to account for those vehicles that are not under the I/M program but which are registered within the county, it was assumed in the Memphis MPO report that 53.95% of the vehicles were subject to the I/M program and 46.05% were not subject to the I/M program. The same assumption has been used in our calculations. As a result, the model was run twice for each year of analysis (except for years 2020 and thereafter): once with an I/M program and once without. The weighted emissions were calculated using Equation 3.2 with f1 and f2 of 0.5395 and 0.4605 respectively. It should be noted that the factors of 53.95% and 46.05% were not used for years 2020 through 2030 analysis years because of the assumption of a county-wide I/M program.

3.3.3.1b. Tipton and Fayette County

These counties do not have an I/M program or an ATP program. VMT fractions developed for the "Shelby +" group were used for these counties. In addition, these two counties use a fuel with RVP of 9.0 psi. Registration distributions, as mentioned earlier, were developed for each subgroup. Hence they did not change between counties within a subgroup or between urban and rural roadway classifications. Speed values did not change between counties but only between urban and rural roadway classifications. Refueling emissions were not considered in the calculations. The Header and Scenario Sections for all the counties remained the same as that of Shelby county and are shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: The emissions were calculated similar to that for Shelby County except that there was no need for an adjustment for the fraction of vehicles that were subject to and not subject to I/M as shown in Equation 3.3.

3.3.3.2. Davidson+ Subgroup

For the Davidson+ subgroup, most of the input parameters were developed based on the information provided in the Nashville MPO's Long Range Transportation Plan. Refueling emissions were not considered in the calculations. Locality specific VMT mix and temperature values were used and were determined as explained earlier. An RVP of 7.8 psi was used based on the ASTM guidance. The input parameters differed slightly for Davidson County and the other four counties. These differences are tabulated in Table D4a through D4d in the appendix. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: Calculations were made consistent with the Nashville MPO Long Range Transportation Plan, and assumed that 76% of the vehicles were subjected to I/M and 24% were not. Hence, the emission calculations were similar to that of Shelby County using Equation 3.2 with the factors being, 0.76 and 0.24 instead of 0.5395 and

0.4605, respectively. This assumption, however, was not used for the other 4 counties. Hence, the calculations for the other 4 counties were similar to that of Tipton and Fayette counties using Equation 3.3.

3.3.3.3. Hamilton+ Subgroup

The input parameters for the Hamilton+ subgroup are shown in Table D5. Refueling emissions were not considered in the calculations. The calculations are based on a 9.0 psi RVP. Both the counties within this subgroup use the same VMT mix determined for this group. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: Since there is no I/M program in Hamilton+ subgroup, the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.4. Knox+ Subgroup

The input parameters for the Knox+ subgroup are shown in Table D6 of the appendix. While the Knoxville MPO has previously included refueling emissions in its plan, the calculations conducted herein do not include those emissions, in an effort to be consistent with all other counties. The calculations are based on a 9.0 psi RVP. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: The calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.5. Sullivan+ Subgroup

The input parameters for Sullivan+ subgroup are shown in Table D7 of the appendix. Refueling emissions were not considered in the calculations. The calculations are based on a 9.0 psi RVP. The Header and Scenario Sections for these counties are as shown in Table D1 and D9 of the appendix, respectively.

Emission Calculations: The calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.6. All Other Counties

The input parameters for all other counties are shown in Table D8 of the appendix. The only differences in the input parameters between the counties within this subgroup were the min/max temperatures and the absolute humidity values depending on the region (east, middle or west) where the county is located, and in some cases a difference in the registration distribution. Most counties used a registration distribution that was developed for this subgroup. However, for those counties whose interstate traffic comprised more than 50% of the total DVMT, the national default registration distribution was used, as discussed earlier. Counties with greater than 50% interstate DVMT include Roane, Cumberland and Campbell Counties in the East Tennessee region;

Putnam, Smith, Robertson and Coffee Counties in the Middle Tennessee region; and Henderson and Haywood Counties in the West Tennessee region. They are shown in italics in Table C1. The calculations are based on a 9.0psi RVP and no I/M program. The Header and Scenario Sections for these counties are as shown in Table D1 and D9 of the appendix, respectively.

Emission Calculations: Since the calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

CHAPTER 4

DISCUSSION OF RESULTS

This chapter summarizes the results of the analyses conducted to estimate emissions of NO_x and VOCs in the State of Tennessee for a typical high ozone summer day. The MOBILE6 model was used to generate emission factors, in terms of grams/mile of vehicle miles traveled. These emission factors, when multiplied by the daily vehicle miles traveled (DVMT), yield the emissions in units of mass/day. Emission projections were done for the years 1999 through 2030. This is to show the effects of new emission standards that will be implemented within the next ten years. Emissions were also projected out to year 2030 to show the effects if no other future standards were implemented. The projections are based on the continued implementation of I/M programs in those counties that currently have I/M programs as required in their respective Long Range Transportation Plans (Shelby, Davidson, Rutherford, Sumner, Williamson and Wilson County). In this study, emission projections were conducted for all 95 counties in the State of Tennessee. Tables E1 through E3 tabulate the emissions for NO_x and VOCs for all the counties in East, Middle and West Tennessee, respectively.

For the purpose of discussion, graphical results of the emission projections are presented for one county from each of the five area subgroups as explained earlier, most of which correspond to a Metropolitan Statistical Area (MSA), and for the State of Tennessee as a whole. These counties are Shelby, Knox, Davidson, Hamilton and Sullivan Counties. The NO_x and VOC baseline emissions for 1999 and future year projections are shown for the five counties in Figures 4-1 through 4-5. Figure 4-6 shows

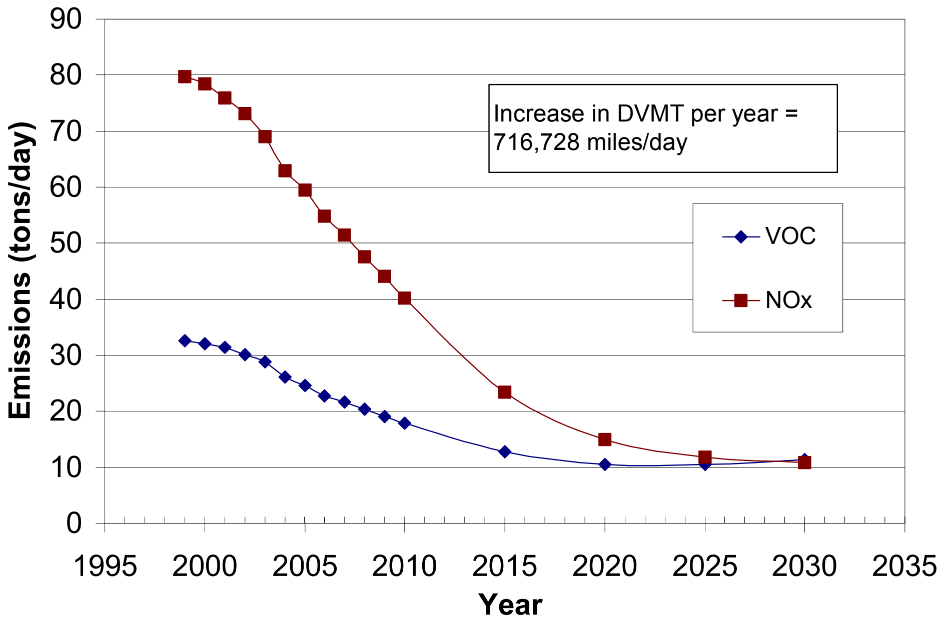

Figure 4-1. Davidson County - Mobile Source Emissions (MOBILE6)

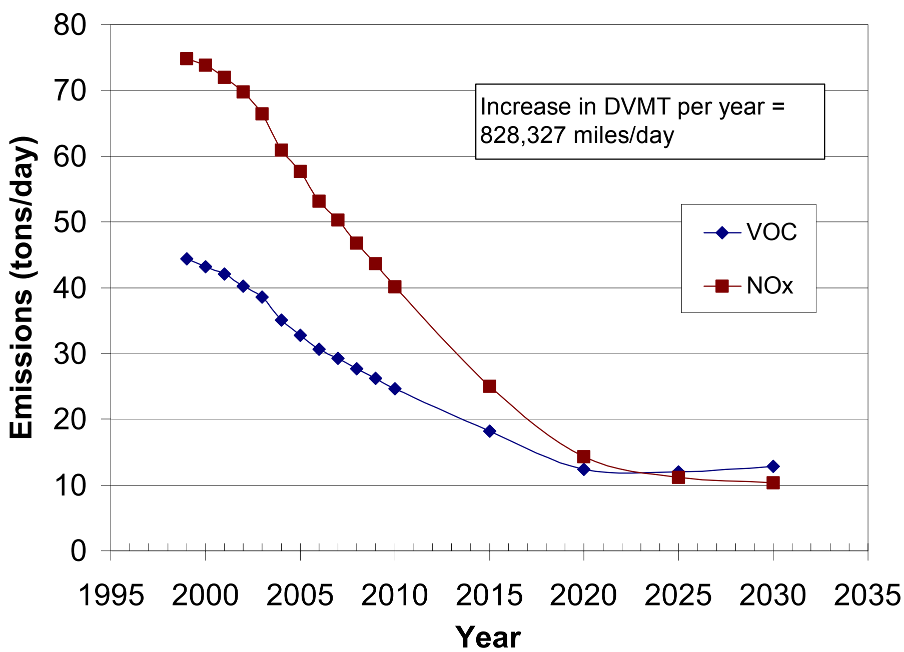

Figure 4-2. Shelby County - Mobile Source Emissions (MOBILE6)

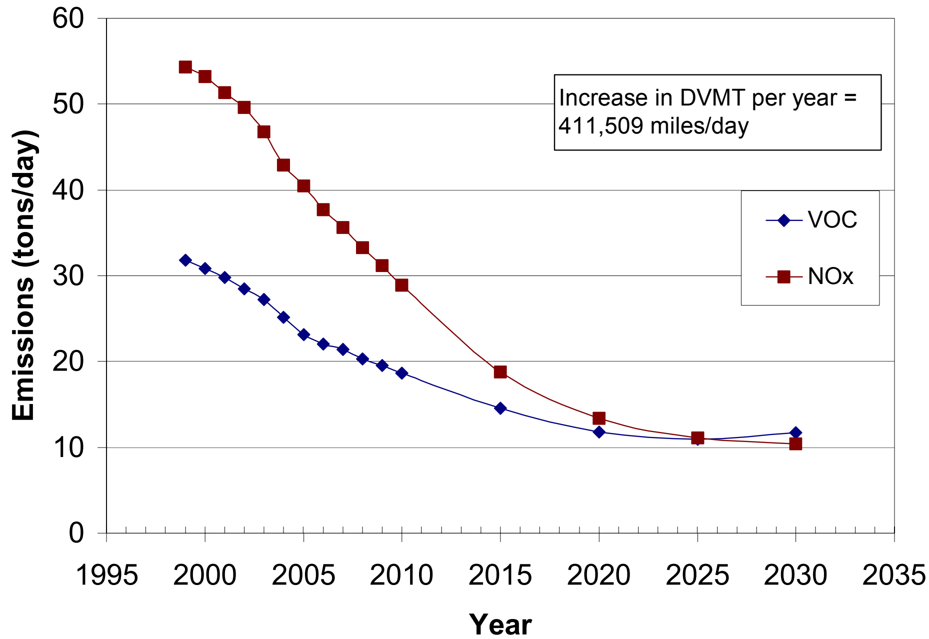

Figure 4-3. Knox County - Mobile Source Emissions (MOBILE6)

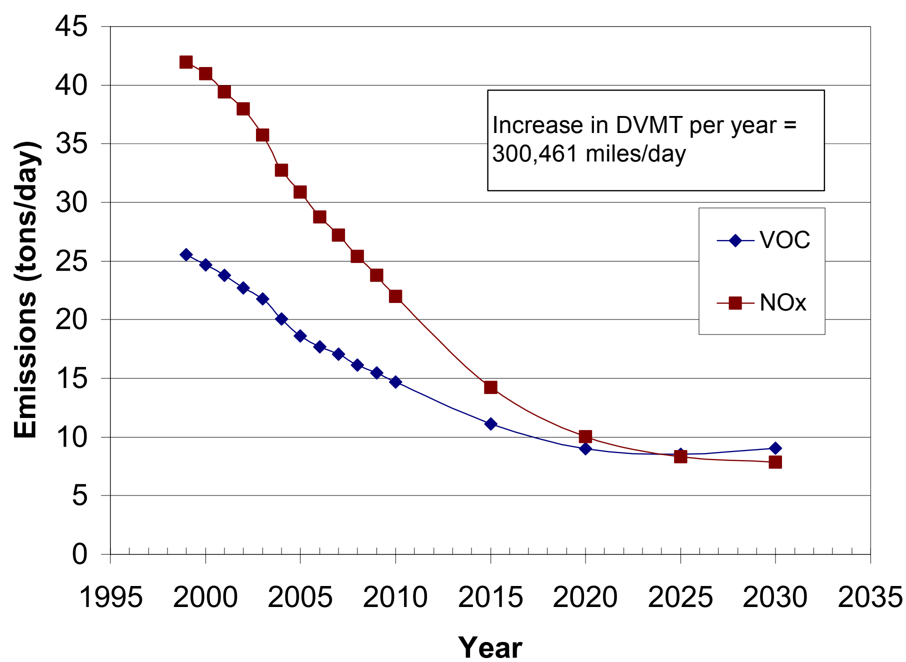

Figure 4-4. Hamilton County - Mobile Source Emissions (MOBILE6)

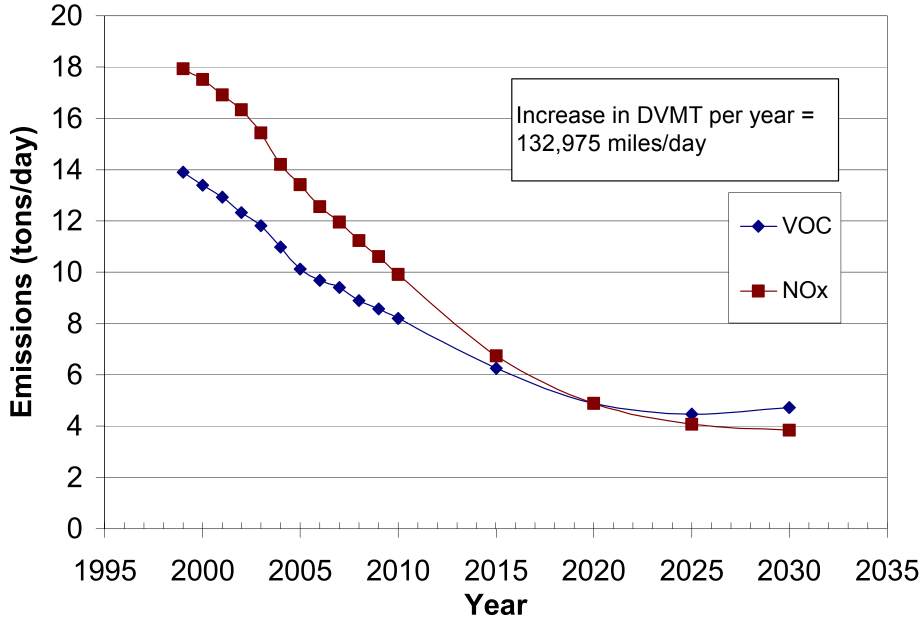

Figure 4-5. Sullivan County - Mobile Source Emissions (MOBILE6)

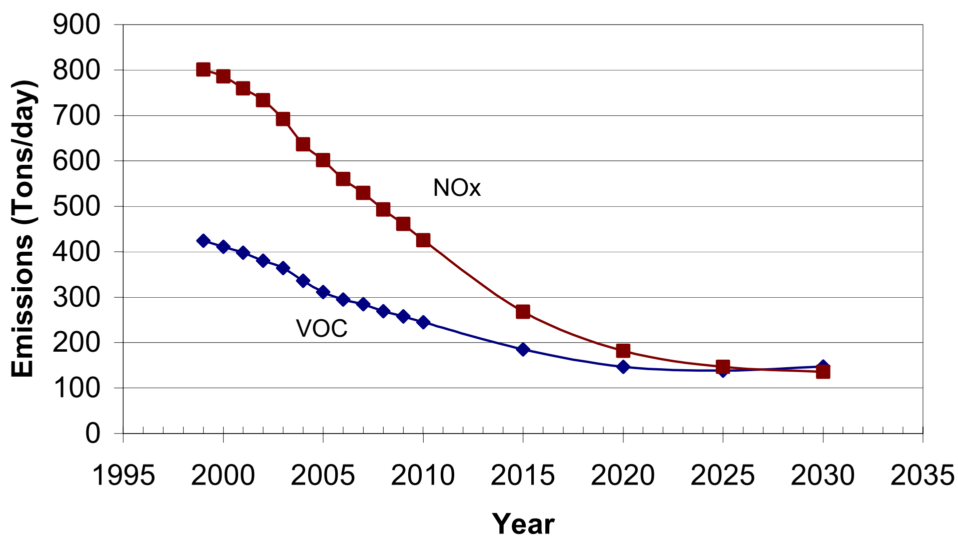

Figure 4-6. Total Projected Emisions in Tennessee (MOBILE6)

the statewide baseline and projected emissions. While the magnitude of the emission levels of these five counties varied considerably due to the different levels of DVMT that occurred in each county, the general trends (relative changes in emission levels in future years compared to the baseline year) for both NO_x and VOC emissions were found to be similar. It was also found that the relative trends were very similar to the other 90 counties in Tennessee. The increase in DVMT each year for the five counties varied from 133,000 to 828,000 miles/day as shown in the figures, while the statewide DVMT increase was 5.8 million miles/day. It was assumed in the calculations that the DVMT increase per year for each county would remain constant in the future and equal to the value determined for the period 1990 through 1999 for that county.

As shown in the figures, NO_x emissions are projected to decrease continuously from the baseline year 1999 to year 2030, with a flattening trend towards year 2030. Similarly, VOC emissions are projected to decrease initially, with an increase after approximately 2020. Emissions of NO_x and VOCs are projected to decrease due to the four new emission standards (LEV, HDDVNO_x, Tier2/Sulfur and HDDV/Sulfur) being implemented during the next ten years. The negative effect of DVMT growth rate overcomes the positive effect of the standards causing a gradual flattening trend in the emissions of NO_x towards the end of year 2030 and a possible increase beyond that period (not shown in graphs) and a projected increase in VOC emissions after year 2020. It is apparent from the emission projections that implementation of the new regulations has less effect on VOC emissions than NO_x emissions.

Shelby County and Davidson County are two of the counties that are subject to I/M programs, whereas the other 3 counties are not currently required to have I/M programs. Shelby County with an I/M program has a 73% projected reduction in VOC emissions and a 85% projected reduction in NO_x emissions by year 2025 and Davidson County with an I/M program has a 68% reduction in VOC and 85% reduction in NO_x emissions by year 2025 as shown in Figures 4-1 and 4-2, respectively. The other 3 counties (Knox, Hamilton and Sullivan County) with no I/M program have projected 66%, 67% and 68% reductions in VOC emissions, respectively, and 80%, 80%, and 77% reductions in NO_x emissions by year 2025 as shown in Figures 4-3, 4-4, and 4-5, respectively.

In an effort to provide some insight into the potential for reducing emissions by implementation of I/M programs (as might be required in the future for counties not yet requiring I/M), a series of calculations was conducted using Davidson County. For illustrative purposes, emissions were recalculated for Davidson County assuming that it had no I/M program and an RVP of 9.0 psi, a scenario which is typical of the counties in Tennessee which have no required I/M program. The emissions were also calculated assuming the I/M program option in MOBILE6 with an RVP of 7.8 psi, a scenario characteristic of a county with an I/M program. For purpose of comparison, it was assumed that even those vehicles which drove through the county but were not registered in that county, were subjected to the I/M program. A comparison of these two different scenarios shows the potential benefit of implementing an I/M program. In Figures 4-7 and 4-8, the emission projections for both NO_x and VOC with and without an I/M program in Davidson County are shown, respectively.

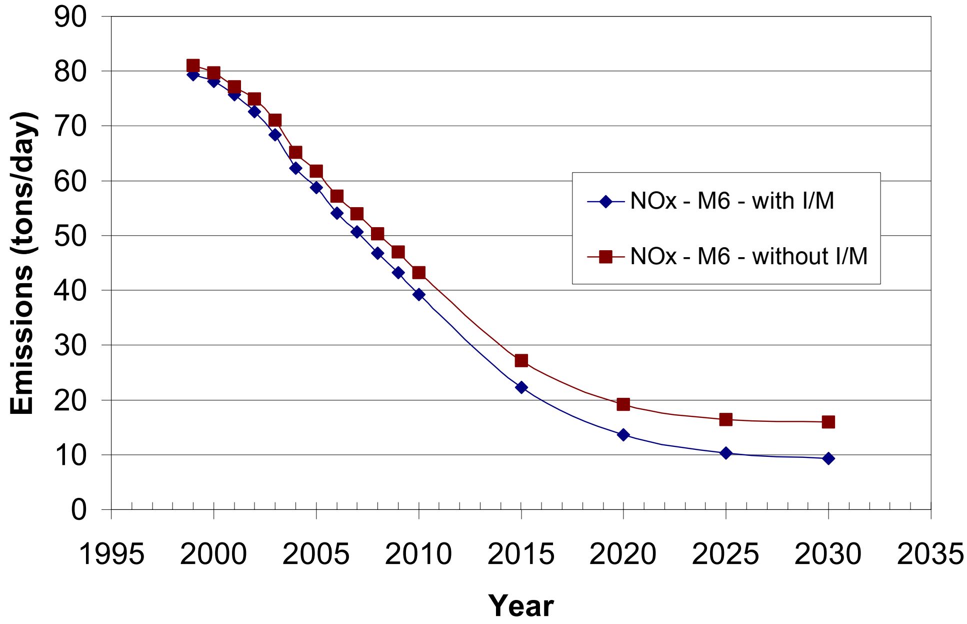

Figure 4-7. Davidson County - NO_x Emissions with and without I/M Program

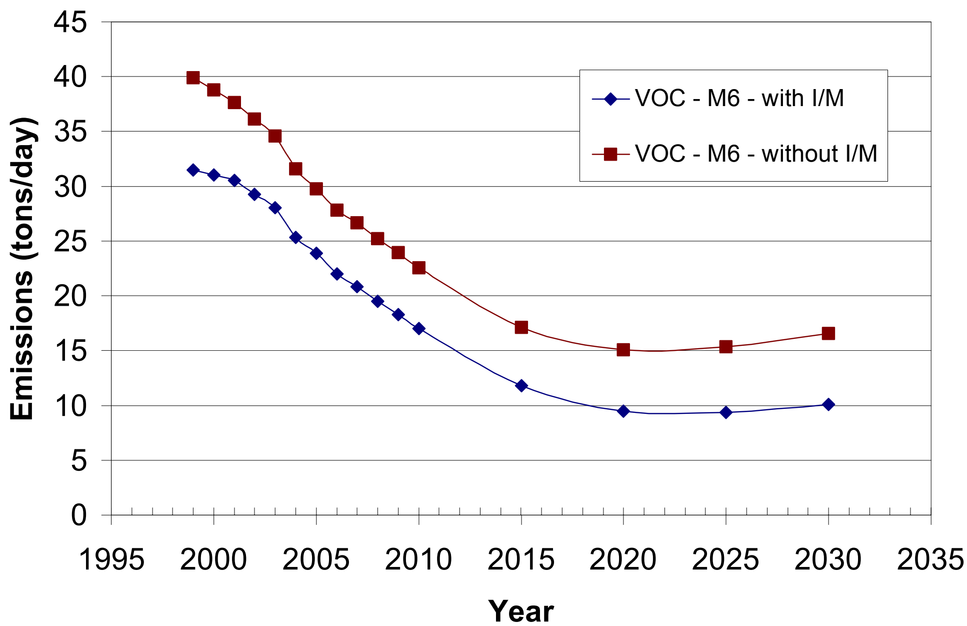

Figure 4-8. Davidson County - VOC Emissions with and without I/M Program

There is a 80% projected reduction in NO_x emissions and a 61% projected reduction in VOC emissions without an I/M program compared to a projected reduction of 87% in NO_x emissions and 70% projected reduction in VOC emissions with an I/M program by year 2025. The percent emission reduction per year that is projected to be achieved through the implementation of an I/M program, as compared to no I/M program, varies from about 2% in 1999 to about 42% in 2030 for NO_x emissions. Similarly, for VOC emissions, the projected emission reduction per year resulting from the implementation of an I/M program varies from about 21% in 1999 to about 39% in 2030 as shown in Figures 4-7 and 4-8, respectively.

A key concern which is often raised is with regard to the rate of growth in VMT which could be sustained without a subsequent increase in emissions. In essence emissions for future years remain constant as long as the VMT growth rate does not exceed the rate at which the composite emission factor is decreasing due to emission standards being implemented. Figures 4-9 and 4-10 show the composite emission factor (g/mile) for 1999-2030 for the conditions shown for Davidson County in the case when I/M is fully implemented for all vehicles. The rapid decrease from 1999 to 2010 followed by a flattening of the curve occurs because more and more of the fleet has been replaced by newer, more efficiently controlled vehicles. Since the current MOBILE model only contains those regulations which are already in place or already planned to go into effect, the curves, become very flat (no significant further reduction after 2025). The approximate rate of change in the composite emission factor (and thus grams/mile) for NO_x and VOC emissions between 2020 and 2030 is approximately –4.4% and –1.3% per year, respectively.

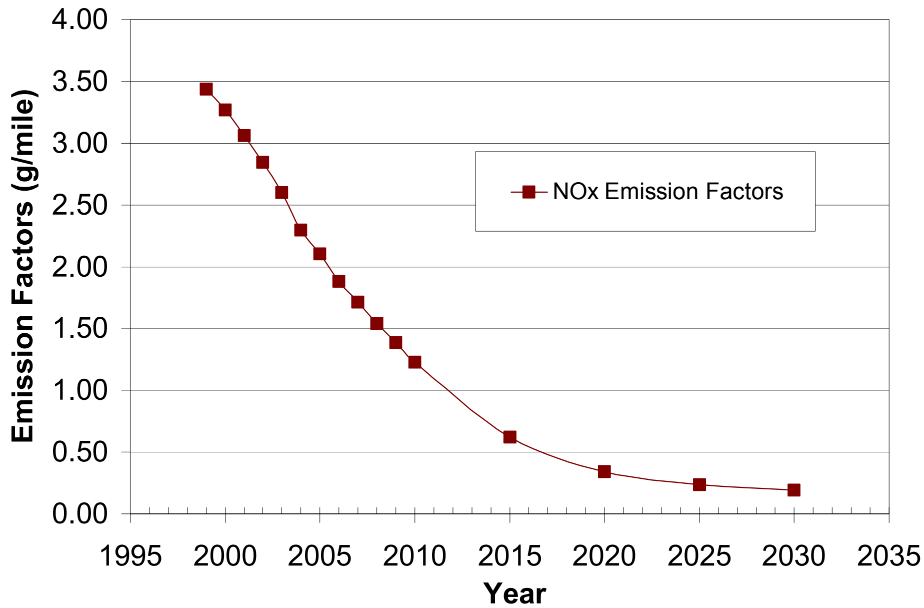

Figure 4-9. Davidson County (with I/M Program) - NO_x Emission Factors vs. Year

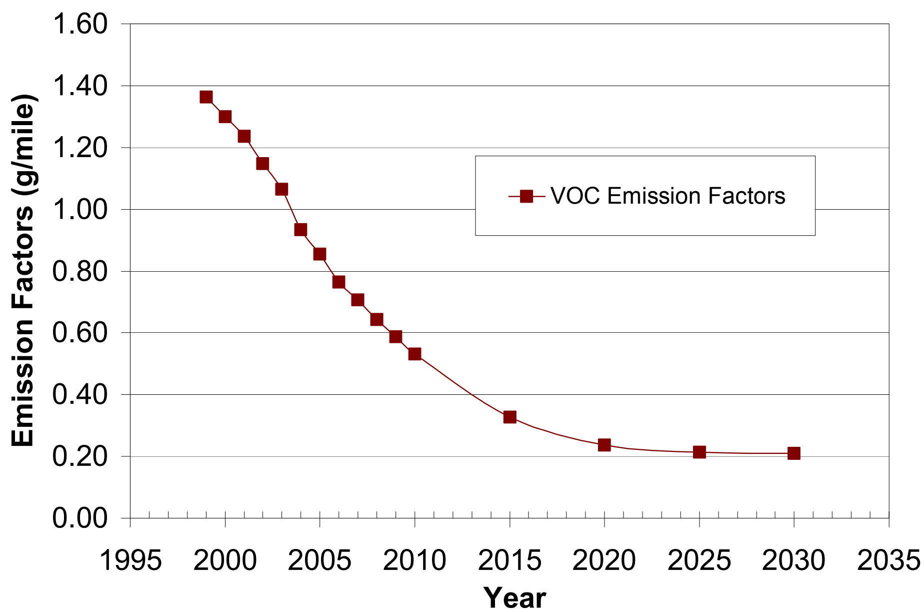

Figure 4-10. Davidson County (with I/M Program) - VOC Emission Factors vs. Year

Therefore, if the DVMT growth rate (rate of linear increase based on 2020 DVMT) remains lower than 4.4%, then the NO_x emissions will continue to decrease. Similarly, if the growth rate remains lower than 1.3%, then the VOC emissions will continue to decrease. For the case of Davidson county, for NO_x emissions, a 4.4% growth rate in DVMT is greater than that of the current linear DVMT growth. Therefore there would not be a problem maintaining the low projected emissions. On the other hand, a linear increase in the DVMT at the rate of less than 1.3% per year would be needed to maintain the decreasing emissions of VOCs based on current emission standards. The graphs (Figures 4-7 and 4-8) show a slight increase in the VOC emissions after 2020 because of the fact that the rate of linear increase in DVMT exceeds 1.3% per year. If this lower growth rate cannot be achieved by 2020, then it is apparent that other strategies would need to be implemented to maintain the VOC emissions at the level achieved by 2020. These include, but are not limited to further tightening of the federal emission standards, and the increased use of vehicles with emissions which are less than allowed under the emission standards at that time, such as hybrid electric and/or zero emission (electric and fuel cell-powered) vehicles. The emission projections in this report do not reflect any benefit from these technologies, since these newer technologies are not required by any federal, State of Tennessee or local regulations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This report has analyzed the effects that the new emission standards (LEV, $HDDVNO_x$, Tier2/Sulfur and HDDV/Sulfur) and DVMT growth will have on the emissions of VOCs and NO_x based on the MOBILE6 model. The study was conducted for the State of Tennessee's Department of Transportation. Emission estimations were made separately for all 95 counties in Tennessee. Example trends have been illustrated by analyzing one county from each area subgroup (Shelby, Knox, Davidson, Hamilton and Sullivan County). The following conclusions were reached in this study:

- Analysis of VMT data for the period 1990 – 1999 for all counties in the State of Tennessee have shown a wide variation in the DVMT growth rate. The linear rate at which the DVMT increased varied from about 6000 miles/day to as high as 828,000 miles/day, depending on the county.
- The new LEV, $HDDVNO_x$, Tier2/Sulfur and HDDV/Sulfur standards, which will be fully in-place by 2001, 2004, 2009, and 2007, respectively, will significantly reduce the emissions of NO_x and VOCs from on-road vehicles. The implementation of the new regulations will have less effect on VOC emissions compared to NO_x emissions.
- While the magnitude of the emission levels of each county vary considerably due to the different levels of DVMT that occur in each area, the general trends (relative changes in emission levels in future years compared to the baseline year 1999) for both NO_x and VOC emissions were found to be very similar.

- NO_x emissions are projected to reach a minimum in approximately 2030 statewide, whereas VOC emissions are expect to reach a minimum by approximately 2020-2025.
- There is a potential for I/M programs to further reduce mobile source emissions of specific counties. There is a 80% reduction in NO_x emissions and a 61% reduction in VOC emissions without an I/M program compared to a reduction of 87% in NO_x emissions and 70% reduction in VOC emissions with an I/M program by year 2025. On the other hand, the year to year projected emission reduction associated with I/M programs compared to the emissions without an I/M program is 2% to 42% for NO_x emissions and 21% to 39% projected reduction for VOC emissions for 1999 and 2030, respectively.

The emission projections contained in this study can be used for further and future analysis. With respect to transportation conformity, these emission projections can be used as a guidance to aid in establishing emission budgets with respect to the new 8-hour ozone standard. The study also shows the effect of an I/M program on the NO_x and VOC emissions. These results can be used as a decision tool for determining whether there is a need for a statewide I/M program versus county specific I/M programs. With the potential of increasing NO_x and VOC emissions in the future due to increasing growth of DVMT, there is also a continuing need to develop strategies which will decrease the growth rate of DVMT, improve emission control technologies, and/or utilize alternative lesser polluting vehicles in order to maintain the lower emissions which are projected to be achieved during the next 10 to 15 years.

The results presented in this study assume a constant linear increase in VMT over the next 30 years. This growth rate in VMT may not continue at the current rates especially if population and the economy do not continue to grow. Future fuel price increases could also significantly affect the VMT growth rate. If VMT growth is reduced, and/or vehicles are utilized which have even less emissions than currently required, then NO_x and VOC emissions may continue to decline beyond 2020.

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REFERENCES

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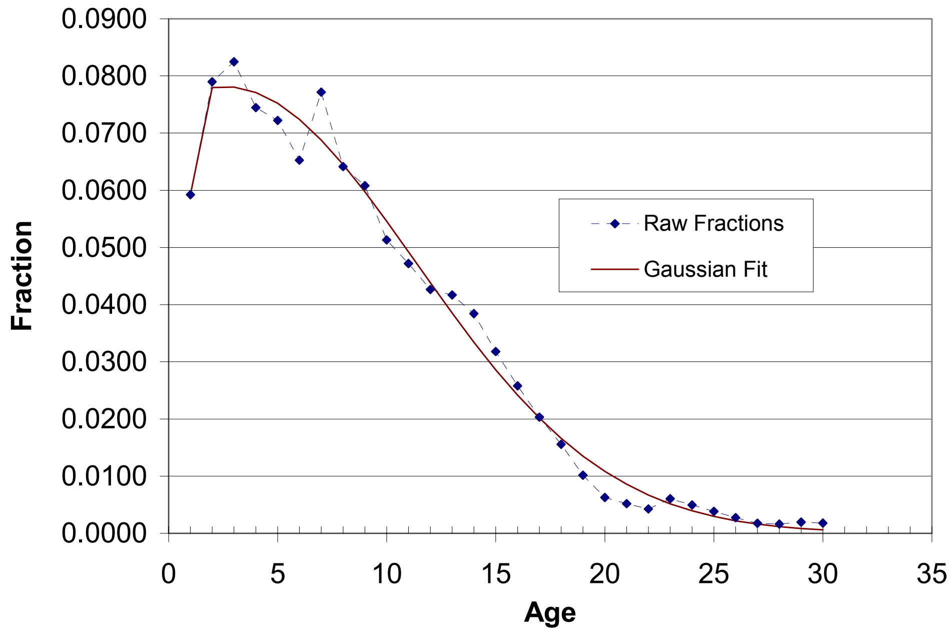
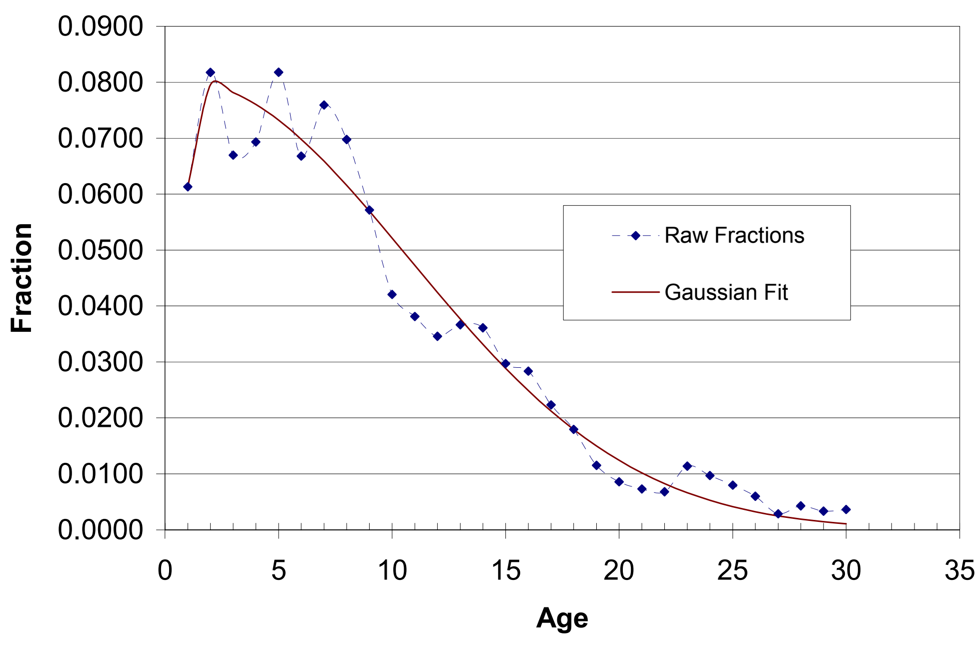
APPENDICES

APPENDIX A

REGISTRATION AGE DISTRIBUTION BEST-FIT GRAPHS

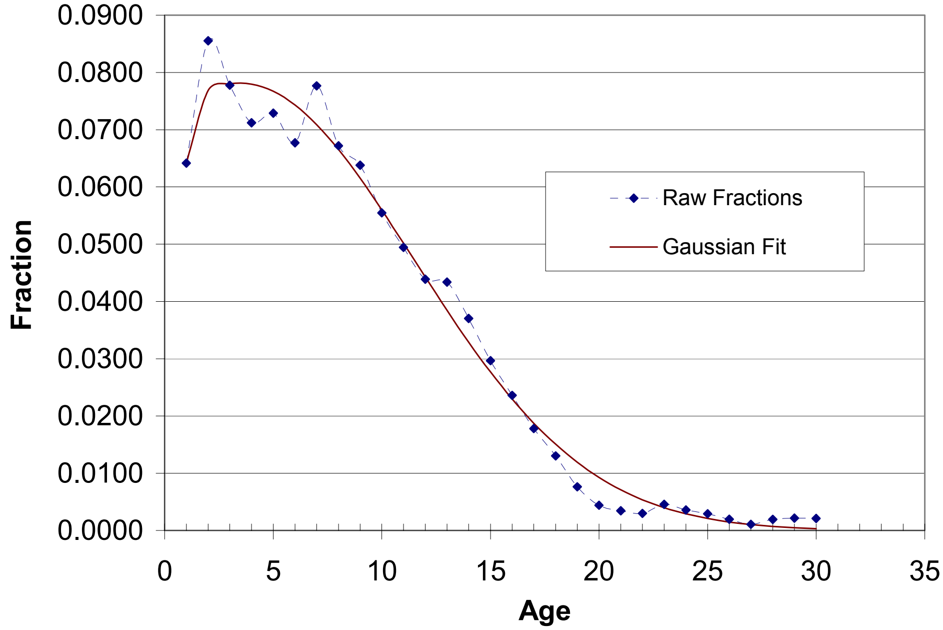


a. LDV Vehicle Classification



b. LDT Vehicle Classification

Figure A1. Registration Distribution for Shelby +



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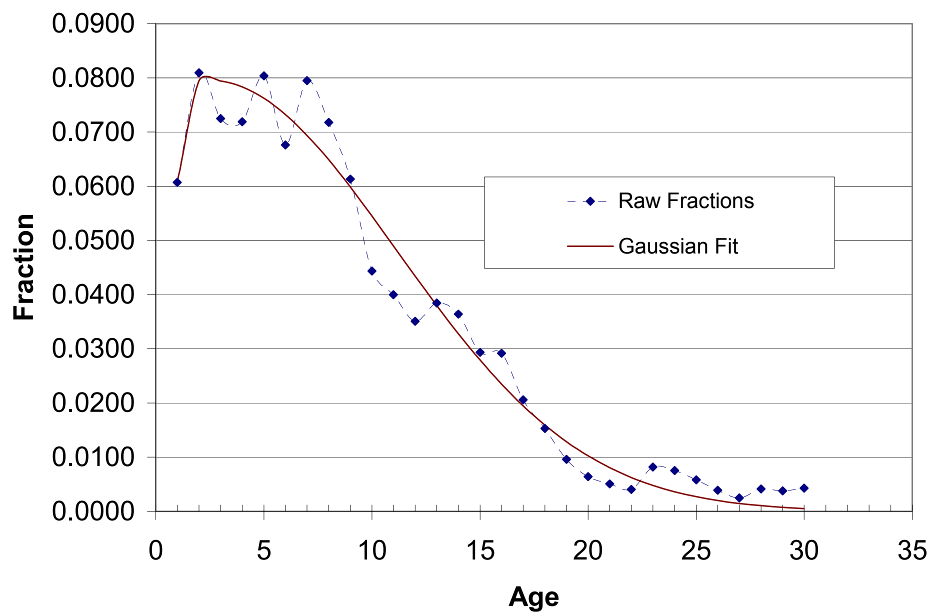
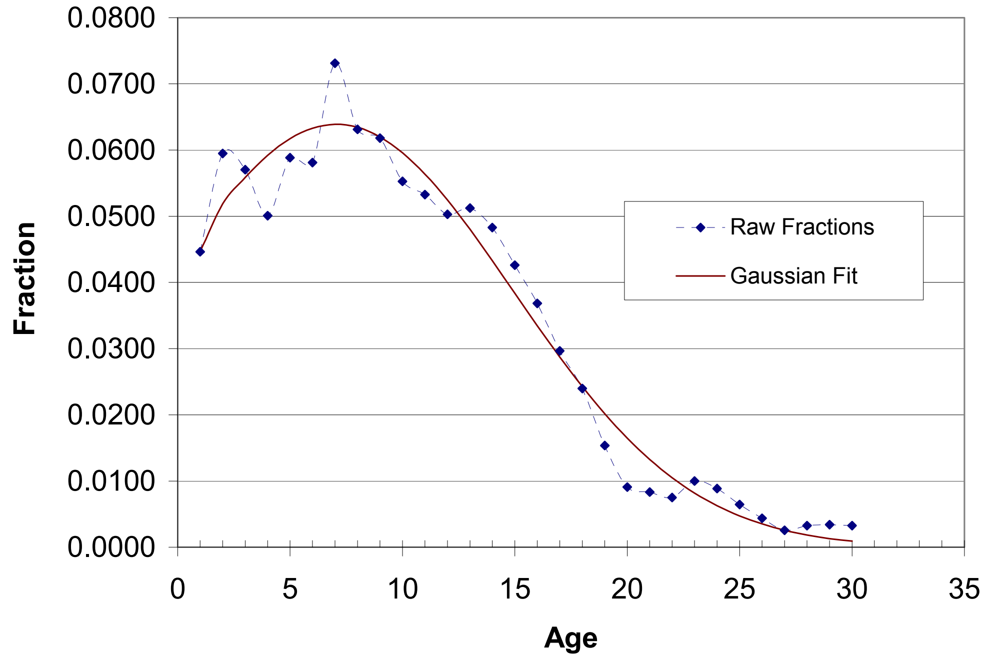


b. LDT Vehicle Classification

Figure A2. Registration Distribution for Davidson +



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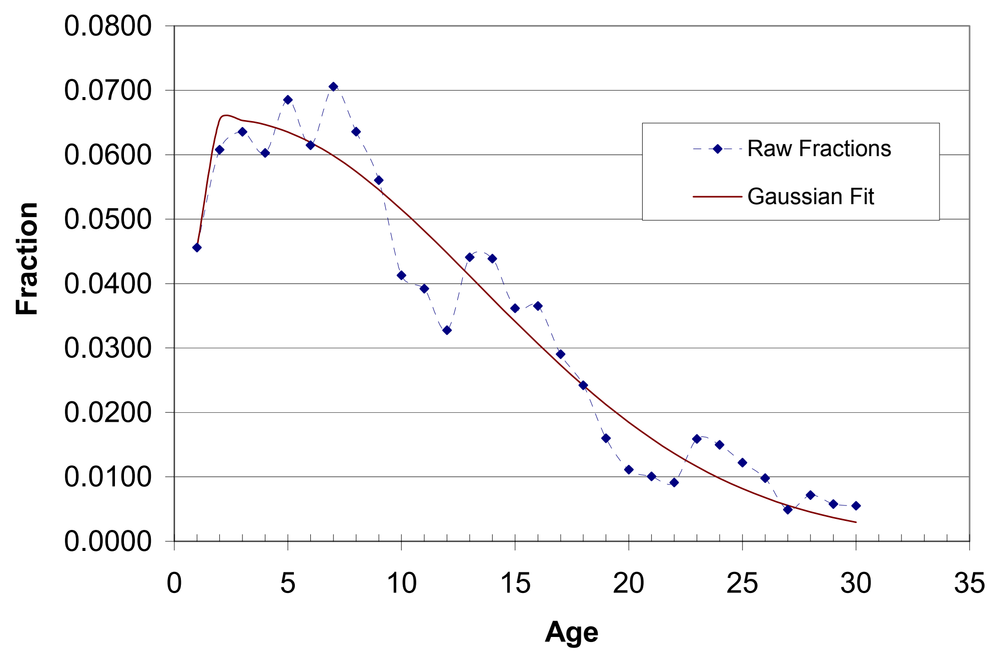
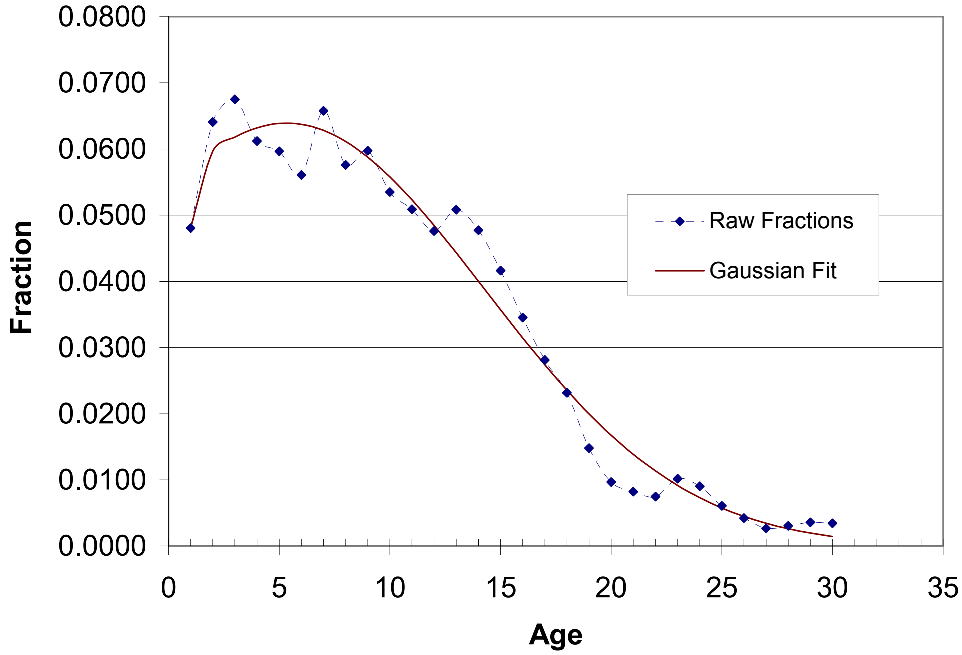


b. LDT Vehicle Classification

Figure A3. Registration Distribution for Hamilton +



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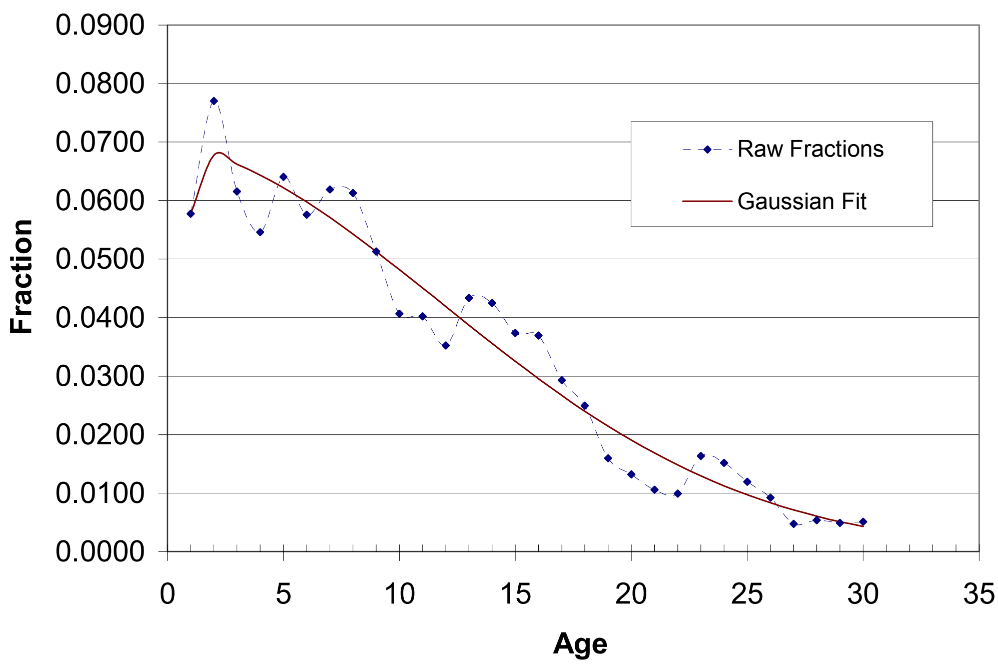
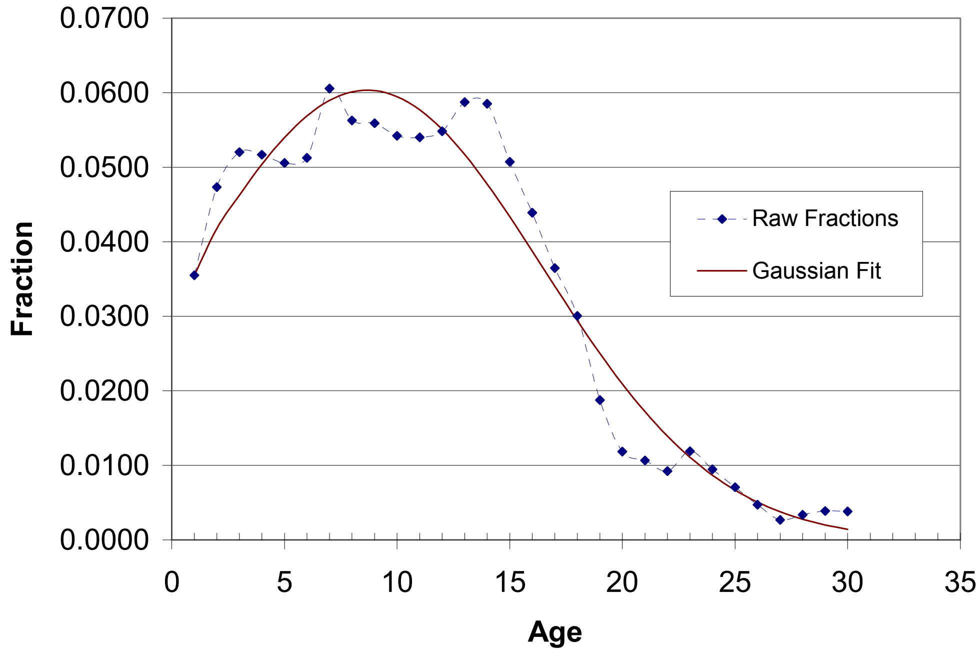
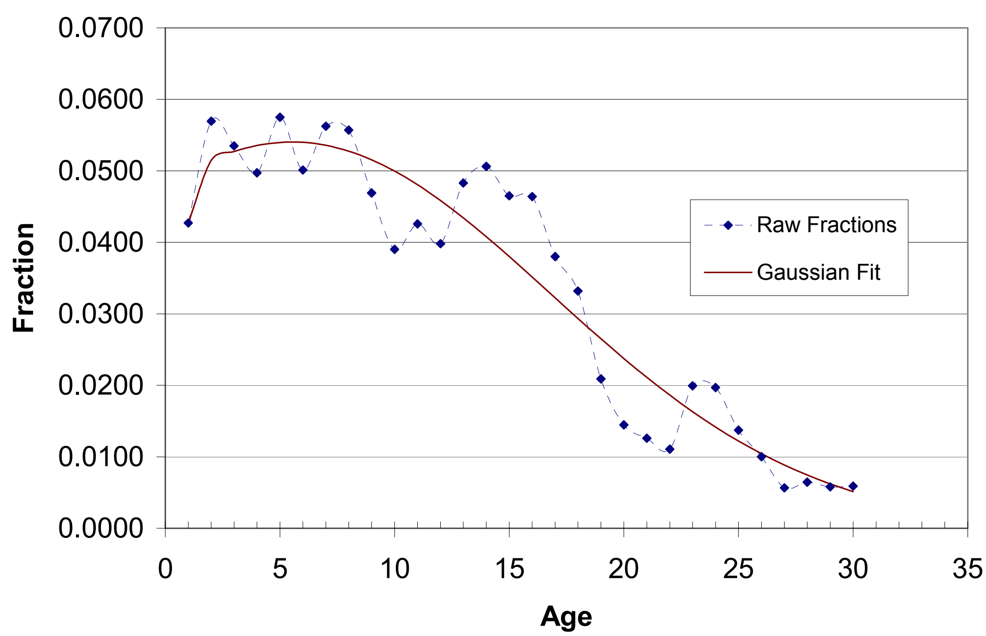


b. LDT Vehicle Classification

Figure A4. Registration Distribution for Knox +

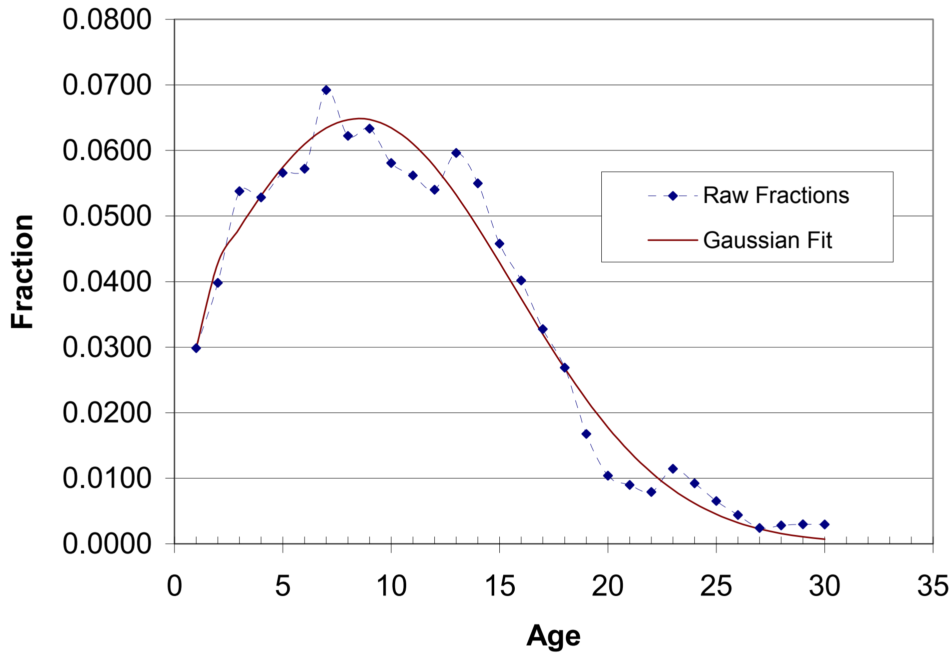


a. LDV Vehicle Classification

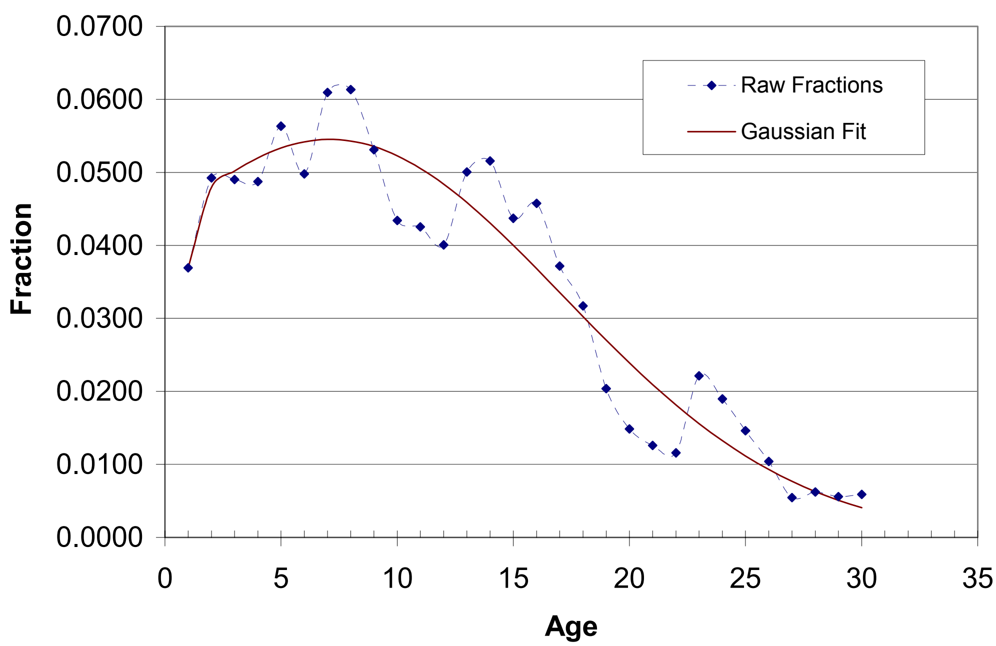


b. LDT Vehicle Classification

Figure A5. Registration Distribution for Sullivan +



a. LDV Vehicle Classification



b. LDT Vehicle Classification

Figure A6. Registration Distribution for All Other Counties

APPENDIX B.1

VEHICLE MILES TRAVELED (VMT) FRACTIONS

Table B.1-1. "Shelby +" VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	Shelby 1998, 1999, 2000	0.578	0.048	0.160	0.049	0.022	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.439	0.037	0.122	0.037	0.017	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.640	0.053	0.177	0.054	0.024	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.630	0.053	0.175	0.054	0.024	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.663	0.055	0.184	0.056	0.025	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.651	0.054	0.180	0.055	0.025	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.552	0.053	0.175	0.054	0.024	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.419	0.040	0.134	0.041	0.018	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.611	0.058	0.194	0.060	0.027	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.602	0.057	0.191	0.059	0.026	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.634	0.060	0.201	0.062	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.621	0.059	0.197	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.526	0.057	0.190	0.058	0.026	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.400	0.044	0.145	0.044	0.020	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.582	0.063	0.210	0.065	0.029	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.574	0.062	0.207	0.064	0.028	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.604	0.065	0.218	0.067	0.030	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.592	0.064	0.214	0.066	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.500	0.062	0.205	0.063	0.028	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.380	0.047	0.156	0.048	0.021	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.553	0.068	0.227	0.070	0.031	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.545	0.067	0.223	0.069	0.031	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.574	0.071	0.235	0.072	0.032	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.563	0.069	0.230	0.071	0.032	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.474	0.066	0.220	0.067	0.030	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.360	0.050	0.167	0.051	0.023	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.525	0.073	0.243	0.075	0.033	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.517	0.072	0.240	0.074	0.033	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.544	0.076	0.252	0.077	0.034	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.534	0.074	0.247	0.076	0.034	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.448	0.070	0.234	0.072	0.032	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.340	0.054	0.179	0.055	0.024	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.496	0.078	0.260	0.080	0.036	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.489	0.077	0.256	0.079	0.035	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.514	0.081	0.269	0.083	0.037	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.505	0.079	0.264	0.081	0.036	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.422	0.075	0.249	0.077	0.034	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.321	0.057	0.190	0.058	0.026	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.467	0.083	0.276	0.085	0.038	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.460	0.082	0.272	0.084	0.037	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.485	0.086	0.286	0.088	0.039	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.475	0.084	0.281	0.086	0.038	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-1. “Shelby +” VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.396	0.079	0.264	0.081	0.036	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.301	0.060	0.201	0.062	0.027	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.438	0.088	0.293	0.090	0.040	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.432	0.087	0.288	0.089	0.039	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.455	0.091	0.303	0.093	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.446	0.089	0.297	0.091	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.370	0.084	0.279	0.086	0.038	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.281	0.064	0.213	0.065	0.029	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.410	0.093	0.309	0.095	0.042	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.404	0.091	0.305	0.094	0.042	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.357	0.086	0.286	0.088	0.039	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.272	0.066	0.218	0.067	0.030	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.396	0.095	0.317	0.098	0.043	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.390	0.094	0.312	0.096	0.043	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.346	0.088	0.293	0.090	0.040	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.263	0.067	0.223	0.069	0.030	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.383	0.097	0.325	0.100	0.044	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.377	0.096	0.320	0.098	0.044	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.303	0.095	0.318	0.098	0.044	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.230	0.073	0.242	0.074	0.033	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.335	0.106	0.352	0.108	0.048	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.330	0.104	0.347	0.107	0.048	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.279	0.099	0.331	0.102	0.045	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.212	0.076	0.252	0.077	0.034	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.367	0.113	0.050	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.050	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.279	0.099	0.331	0.102	0.045	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.212	0.076	0.252	0.077	0.034	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.367	0.113	0.050	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.050	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.279	0.099	0.331	0.102	0.045	0.032	0	0	0	0	0	0.025	0.084	0	0	0.002	1.000
Rural Interstates		0.212	0.076	0.252	0.077	0.034	0.078	0	0	0	0	0	0.061	0.201	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.367	0.113	0.050	0.011	0	0	0	0	0	0.009	0.028	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.050	0.014	0	0	0	0	0	0.011	0.035	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-2. "Knox +" VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	Knox 1998, 1999, 2000	0.487	0.062	0.207	0.064	0.028	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.444	0.057	0.189	0.058	0.026	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.547	0.070	0.233	0.072	0.032	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.525	0.067	0.224	0.069	0.031	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.565	0.072	0.240	0.074	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.554	0.071	0.236	0.072	0.032	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.472	0.065	0.216	0.066	0.030	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.430	0.059	0.197	0.061	0.027	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.531	0.073	0.243	0.075	0.033	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.509	0.070	0.233	0.072	0.032	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.547	0.075	0.250	0.077	0.034	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.537	0.074	0.245	0.076	0.034	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.457	0.068	0.225	0.069	0.031	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.416	0.062	0.205	0.063	0.028	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.514	0.076	0.252	0.078	0.035	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.493	0.073	0.243	0.075	0.033	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.530	0.078	0.260	0.080	0.036	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.520	0.077	0.255	0.079	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.442	0.070	0.233	0.072	0.032	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.403	0.064	0.213	0.065	0.029	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.497	0.079	0.262	0.081	0.036	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.477	0.076	0.252	0.077	0.034	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.512	0.081	0.270	0.083	0.037	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.502	0.080	0.265	0.082	0.036	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.427	0.073	0.242	0.074	0.033	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.389	0.066	0.221	0.068	0.030	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.480	0.082	0.272	0.084	0.037	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.460	0.078	0.261	0.080	0.036	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.495	0.084	0.280	0.086	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.485	0.083	0.275	0.085	0.038	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.412	0.075	0.251	0.077	0.034	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.375	0.069	0.229	0.070	0.031	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.463	0.085	0.281	0.087	0.039	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.444	0.081	0.270	0.083	0.037	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.477	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.468	0.086	0.285	0.088	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.397	0.078	0.259	0.080	0.035	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.361	0.071	0.236	0.073	0.032	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials		0.446	0.087	0.291	0.090	0.040	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.428	0.084	0.280	0.086	0.038	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.460	0.090	0.300	0.092	0.041	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.451	0.088	0.294	0.091	0.040	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-2. "Knox +" VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates		0.382	0.080	0.268	0.082	0.037	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.348	0.073	0.244	0.075	0.033	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2007	0.429	0.090	0.301	0.093	0.041	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.412	0.087	0.289	0.089	0.040	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.443	0.093	0.310	0.095	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.434	0.091	0.304	0.094	0.042	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.367	0.083	0.276	0.085	0.038	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.334	0.076	0.252	0.077	0.034	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2008	0.412	0.093	0.310	0.096	0.043	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.395	0.090	0.298	0.092	0.041	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.354	0.085	0.284	0.087	0.039	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.323	0.078	0.259	0.080	0.035	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2009	0.398	0.096	0.319	0.098	0.044	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.382	0.092	0.306	0.094	0.042	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.343	0.087	0.290	0.089	0.040	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.312	0.080	0.265	0.081	0.036	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2010	0.385	0.098	0.326	0.100	0.045	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.369	0.094	0.313	0.096	0.043	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.300	0.095	0.315	0.097	0.043	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.273	0.086	0.287	0.088	0.039	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2015	0.337	0.106	0.354	0.109	0.048	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.323	0.102	0.340	0.105	0.047	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.277	0.099	0.328	0.101	0.045	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.252	0.090	0.299	0.092	0.041	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2020	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.298	0.106	0.354	0.109	0.048	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.277	0.099	0.328	0.101	0.045	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.252	0.090	0.299	0.092	0.041	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2025	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.298	0.106	0.354	0.109	0.048	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.277	0.099	0.328	0.101	0.045	0.034	0	0	0	0	0	0.027	0.088	0	0	0.002	1.000
Rural Interstates		0.252	0.090	0.299	0.092	0.041	0.050	0	0	0	0	0	0.039	0.129	0	0	0.008	1.000
Urban Arterials	2030	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.002	1.000
Rural Arterials		0.298	0.106	0.354	0.109	0.048	0.018	0	0	0	0	0	0.014	0.047	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-3. "Hamilton +" VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates		0.482	0.056	0.187	0.058	0.026	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates	**Hamilton**	0.436	0.051	0.170	0.052	0.023	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials	**1998,**	0.568	0.066	0.220	0.068	0.030	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**1999,**	0.551	0.064	0.214	0.066	0.029	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local	**2000**	0.587	0.068	0.227	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.576	0.067	0.223	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.466	0.059	0.197	0.060	0.027	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.421	0.054	0.178	0.055	0.024	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.549	0.069	0.231	0.071	0.032	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2001**	0.532	0.067	0.225	0.069	0.031	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.567	0.072	0.239	0.074	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.556	0.070	0.234	0.072	0.032	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.449	0.062	0.206	0.063	0.028	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.406	0.056	0.187	0.057	0.026	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.529	0.073	0.242	0.075	0.033	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2002**	0.513	0.071	0.236	0.072	0.032	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.547	0.075	0.251	0.077	0.034	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.536	0.074	0.246	0.076	0.034	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.432	0.065	0.216	0.066	0.030	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.391	0.059	0.196	0.060	0.027	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.509	0.076	0.254	0.078	0.035	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2003**	0.494	0.074	0.246	0.076	0.034	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.526	0.079	0.262	0.081	0.036	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.516	0.077	0.257	0.079	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.416	0.068	0.225	0.069	0.031	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.376	0.061	0.204	0.063	0.028	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.490	0.080	0.265	0.081	0.036	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2004**	0.475	0.077	0.257	0.079	0.035	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.506	0.082	0.274	0.084	0.037	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.399	0.071	0.235	0.072	0.032	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.361	0.064	0.213	0.065	0.029	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.470	0.083	0.276	0.085	0.038	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2005**	0.456	0.081	0.268	0.082	0.037	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.486	0.086	0.285	0.088	0.039	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.477	0.084	0.280	0.086	0.038	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.382	0.073	0.245	0.075	0.033	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.346	0.067	0.222	0.068	0.030	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.451	0.086	0.287	0.088	0.039	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials	**2006**	0.437	0.084	0.279	0.086	0.038	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.466	0.089	0.297	0.091	0.041	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.457	0.088	0.291	0.090	0.040	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-3. "Hamilton +" VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.366	0.076	0.254	0.078	0.035	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.331	0.069	0.230	0.071	0.031	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.431	0.090	0.299	0.092	0.041	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.418	0.087	0.290	0.089	0.040	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.445	0.093	0.309	0.095	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.437	0.091	0.303	0.093	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.349	0.079	0.264	0.081	0.036	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.315	0.072	0.239	0.073	0.033	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.411	0.093	0.310	0.095	0.042	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.399	0.090	0.301	0.093	0.041	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.337	0.081	0.271	0.083	0.037	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.305	0.074	0.245	0.075	0.033	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.397	0.095	0.318	0.098	0.044	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.385	0.093	0.309	0.095	0.042	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.326	0.083	0.277	0.085	0.038	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.295	0.075	0.251	0.077	0.034	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.384	0.098	0.325	0.100	0.045	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.373	0.095	0.316	0.097	0.043	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.285	0.090	0.300	0.092	0.041	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.258	0.082	0.272	0.084	0.037	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.336	0.106	0.353	0.109	0.048	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.326	0.103	0.343	0.105	0.047	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.263	0.094	0.313	0.096	0.043	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.238	0.085	0.283	0.087	0.039	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.310	0.110	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.301	0.107	0.357	0.110	0.049	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.263	0.094	0.313	0.096	0.043	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.238	0.085	0.283	0.087	0.039	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.310	0.110	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.301	0.107	0.357	0.110	0.049	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.263	0.094	0.313	0.096	0.043	0.043	0	0	0	0	0	0.034	0.112	0	0	0.002	1.000
Rural Interstates		0.238	0.085	0.283	0.087	0.039	0.060	0	0	0	0	0	0.046	0.154	0	0	0.008	1.000
Urban Arterials		0.310	0.110	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.027	0	0	0.003	1.000
Rural Arterials		0.301	0.107	0.357	0.110	0.049	0.016	0	0	0	0	0	0.013	0.042	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-4. Davidson County VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates		0.550	0.051	0.171	0.052	0.023	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates	**Davidson**	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**1998,**	0.613	0.057	0.190	0.058	0.026	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials	**1999,**	0.591	0.055	0.183	0.056	0.025	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local	**2000**	0.639	0.059	0.198	0.061	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.627	0.058	0.194	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.526	0.055	0.184	0.056	0.025	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2001**	0.587	0.061	0.205	0.063	0.028	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.567	0.059	0.197	0.061	0.027	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.612	0.064	0.213	0.065	0.029	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.600	0.063	0.209	0.064	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.503	0.059	0.197	0.060	0.027	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2002**	0.561	0.066	0.219	0.067	0.030	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.542	0.064	0.212	0.065	0.029	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.585	0.069	0.228	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.574	0.067	0.224	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.480	0.063	0.210	0.065	0.029	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2003**	0.536	0.070	0.234	0.072	0.032	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.517	0.068	0.226	0.069	0.031	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.559	0.073	0.244	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.548	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.457	0.067	0.223	0.069	0.031	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2004**	0.510	0.075	0.249	0.076	0.034	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.492	0.072	0.240	0.074	0.033	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.532	0.078	0.259	0.080	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.522	0.076	0.254	0.078	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.434	0.071	0.237	0.073	0.032	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2005**	0.484	0.079	0.263	0.081	0.036	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.468	0.076	0.254	0.078	0.035	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.505	0.082	0.274	0.084	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.411	0.075	0.250	0.077	0.034	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials	**2006**	0.459	0.084	0.278	0.086	0.038	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.443	0.081	0.268	0.083	0.037	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.479	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.469	0.085	0.284	0.087	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-4. Davidson County VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.388	0.079	0.263	0.081	0.036	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.433	0.088	0.293	0.090	0.040	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.418	0.085	0.283	0.087	0.039	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.452	0.092	0.305	0.094	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.443	0.090	0.299	0.092	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.365	0.083	0.276	0.085	0.038	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.407	0.092	0.308	0.095	0.042	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.393	0.089	0.297	0.091	0.041	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.353	0.085	0.283	0.087	0.039	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.393	0.095	0.316	0.097	0.043	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.380	0.091	0.304	0.094	0.042	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.341	0.087	0.290	0.089	0.040	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.381	0.097	0.323	0.099	0.044	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.367	0.094	0.312	0.096	0.043	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.298	0.094	0.314	0.097	0.043	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.333	0.105	0.350	0.108	0.048	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.321	0.102	0.338	0.104	0.046	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.275	0.098	0.328	0.101	0.045	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.307	0.110	0.365	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.297	0.106	0.352	0.108	0.048	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.275	0.098	0.328	0.101	0.045	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.307	0.110	0.365	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.297	0.106	0.352	0.108	0.048	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.275	0.098	0.328	0.101	0.045	0.035	0	0	0	0	0	0.027	0.089	0	0	0.002	1.000
Rural Interstates		0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0	0	0.000	0.000	0	0	0.000	0.000
Urban Arterials		0.307	0.110	0.365	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.003	1.000
Rural Arterials		0.297	0.106	0.352	0.108	0.048	0.019	0	0	0	0	0	0.015	0.050	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-5. Rutherford County VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	Rutherford 1998, 1999, 2000	0.483	0.045	0.150	0.046	0.020	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.477	0.045	0.148	0.045	0.020	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.620	0.058	0.192	0.059	0.026	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.611	0.057	0.190	0.058	0.026	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.639	0.059	0.198	0.061	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.627	0.058	0.194	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.463	0.048	0.161	0.049	0.022	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.457	0.048	0.160	0.049	0.022	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.594	0.062	0.207	0.064	0.028	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.586	0.061	0.204	0.063	0.028	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.612	0.064	0.213	0.065	0.029	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.600	0.063	0.209	0.064	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.442	0.052	0.173	0.053	0.024	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.437	0.051	0.171	0.052	0.023	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.568	0.067	0.222	0.068	0.030	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.560	0.066	0.219	0.067	0.030	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.585	0.069	0.228	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.574	0.067	0.224	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.422	0.055	0.185	0.057	0.025	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.417	0.055	0.183	0.056	0.025	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.542	0.071	0.237	0.073	0.032	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.535	0.070	0.234	0.072	0.032	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.559	0.073	0.244	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.548	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.402	0.059	0.196	0.060	0.027	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.397	0.058	0.194	0.060	0.026	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.516	0.076	0.251	0.077	0.034	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.509	0.075	0.248	0.076	0.034	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.532	0.078	0.259	0.080	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.522	0.076	0.254	0.078	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.382	0.062	0.208	0.064	0.028	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.377	0.062	0.205	0.063	0.028	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.490	0.080	0.266	0.082	0.036	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.483	0.079	0.263	0.081	0.036	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.505	0.082	0.274	0.084	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.362	0.066	0.219	0.067	0.030	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.357	0.065	0.217	0.067	0.030	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.465	0.084	0.281	0.086	0.038	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.458	0.083	0.278	0.085	0.038	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.479	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.469	0.085	0.284	0.087	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-5. Rutherford County VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.341	0.069	0.231	0.071	0.032	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.337	0.069	0.228	0.070	0.031	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.439	0.089	0.296	0.091	0.041	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.432	0.088	0.292	0.090	0.040	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.452	0.092	0.305	0.094	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.443	0.090	0.299	0.092	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.321	0.073	0.242	0.074	0.033	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.317	0.072	0.240	0.074	0.033	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.413	0.093	0.311	0.096	0.043	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.407	0.092	0.307	0.094	0.042	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.310	0.075	0.249	0.076	0.034	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.306	0.074	0.246	0.076	0.034	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.399	0.096	0.319	0.098	0.044	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.393	0.095	0.315	0.097	0.043	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.300	0.076	0.254	0.078	0.035	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.296	0.076	0.252	0.077	0.034	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.386	0.098	0.326	0.100	0.045	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.380	0.097	0.322	0.099	0.044	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.262	0.083	0.276	0.085	0.038	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.259	0.082	0.273	0.084	0.037	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.337	0.106	0.354	0.109	0.048	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.332	0.105	0.349	0.108	0.048	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.242	0.086	0.288	0.088	0.039	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.239	0.085	0.284	0.087	0.039	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.311	0.111	0.369	0.114	0.051	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.307	0.109	0.364	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.242	0.086	0.288	0.088	0.039	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.239	0.085	0.284	0.087	0.039	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.311	0.111	0.369	0.114	0.051	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.307	0.109	0.364	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.242	0.086	0.288	0.088	0.039	0.058	0	0	0	0	0	0.045	0.151	0	0	0.002	1.000
Rural Interstates		0.239	0.085	0.284	0.087	0.039	0.059	0	0	0	0	0	0.046	0.152	0	0	0.008	1.000
Urban Arterials		0.311	0.111	0.369	0.114	0.051	0.010	0	0	0	0	0	0.007	0.025	0	0	0.003	1.000
Rural Arterials		0.307	0.109	0.364	0.112	0.050	0.012	0	0	0	0	0	0.009	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-6. Sumner County VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	**Sumner 1998, 1999, 2000**	0.466	0.043	0.145	0.044	0.020	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.463	0.043	0.143	0.044	0.020	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.604	0.056	0.187	0.057	0.026	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.618	0.057	0.191	0.059	0.026	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.639	0.059	0.198	0.061	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.627	0.058	0.194	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2001**	0.446	0.047	0.156	0.048	0.021	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.443	0.046	0.154	0.047	0.021	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.578	0.061	0.202	0.062	0.028	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.592	0.062	0.206	0.063	0.028	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.612	0.064	0.213	0.065	0.029	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.600	0.063	0.209	0.064	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2002**	0.427	0.050	0.167	0.051	0.023	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.424	0.050	0.165	0.051	0.023	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.553	0.065	0.216	0.066	0.030	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.566	0.066	0.221	0.068	0.030	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.585	0.069	0.228	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.574	0.067	0.224	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2003**	0.407	0.054	0.178	0.055	0.024	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.405	0.053	0.176	0.054	0.024	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.528	0.069	0.231	0.071	0.032	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.540	0.071	0.236	0.072	0.032	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.559	0.073	0.244	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.548	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2004**	0.388	0.057	0.190	0.058	0.026	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.385	0.056	0.187	0.058	0.026	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.503	0.074	0.245	0.075	0.034	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.514	0.075	0.250	0.077	0.034	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.532	0.078	0.259	0.080	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.522	0.076	0.254	0.078	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2005**	0.368	0.060	0.201	0.062	0.027	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.366	0.060	0.198	0.061	0.027	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.477	0.078	0.260	0.080	0.036	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.488	0.080	0.265	0.082	0.036	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.505	0.082	0.274	0.084	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2006**	0.349	0.064	0.212	0.065	0.029	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.347	0.063	0.209	0.064	0.029	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.452	0.082	0.274	0.084	0.037	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.463	0.084	0.280	0.086	0.038	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.479	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.469	0.085	0.284	0.087	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-6. Sumner County VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	**2007**	0.329	0.067	0.223	0.068	0.030	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.327	0.066	0.220	0.068	0.030	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.427	0.087	0.288	0.089	0.039	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.437	0.089	0.295	0.091	0.040	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.452	0.092	0.305	0.094	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.443	0.090	0.299	0.092	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2008**	0.309	0.070	0.234	0.072	0.032	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.308	0.070	0.231	0.071	0.032	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.401	0.091	0.303	0.093	0.041	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.411	0.093	0.309	0.095	0.042	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2009**	0.299	0.072	0.240	0.074	0.033	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.297	0.071	0.238	0.073	0.033	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.388	0.093	0.311	0.096	0.043	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.397	0.095	0.318	0.098	0.043	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2010**	0.289	0.074	0.246	0.076	0.034	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.288	0.073	0.243	0.075	0.033	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.375	0.096	0.318	0.098	0.044	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.384	0.098	0.325	0.100	0.044	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2015**	0.253	0.080	0.267	0.082	0.036	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.252	0.079	0.264	0.081	0.036	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.328	0.104	0.345	0.106	0.047	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.336	0.106	0.352	0.108	0.048	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2020**	0.233	0.083	0.278	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.232	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.303	0.108	0.359	0.111	0.049	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.310	0.110	0.367	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2025**	0.233	0.083	0.278	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.232	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.303	0.108	0.359	0.111	0.049	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.310	0.110	0.367	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2030**	0.233	0.083	0.278	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.002	1.000
Rural Interstates		0.232	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.166	0	0	0.008	1.000
Urban Arterials		0.303	0.108	0.359	0.111	0.049	0.015	0	0	0	0	0	0.012	0.040	0	0	0.003	1.000
Rural Arterials		0.310	0.110	0.367	0.113	0.050	0.010	0	0	0	0	0	0.008	0.026	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-7. Williamson County VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	Williamson 1998, 1999, 2000	0.554	0.052	0.172	0.053	0.023	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.482	0.045	0.150	0.046	0.020	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.620	0.058	0.192	0.059	0.026	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.623	0.058	0.193	0.059	0.026	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.639	0.059	0.198	0.061	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.627	0.058	0.194	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.531	0.056	0.185	0.057	0.025	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.462	0.048	0.161	0.049	0.022	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.594	0.062	0.207	0.063	0.028	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.597	0.062	0.208	0.064	0.028	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.612	0.064	0.213	0.065	0.029	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.600	0.063	0.209	0.064	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.508	0.060	0.198	0.061	0.027	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.442	0.052	0.173	0.053	0.024	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.568	0.067	0.221	0.068	0.030	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.571	0.067	0.223	0.068	0.030	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.585	0.069	0.228	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.574	0.067	0.224	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.485	0.064	0.212	0.065	0.029	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.422	0.055	0.184	0.057	0.025	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.542	0.071	0.236	0.073	0.032	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.545	0.071	0.238	0.073	0.032	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.559	0.073	0.244	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.548	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.462	0.068	0.225	0.069	0.031	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.401	0.059	0.196	0.060	0.027	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.516	0.075	0.251	0.077	0.034	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.519	0.076	0.252	0.078	0.035	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.532	0.078	0.259	0.080	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.522	0.076	0.254	0.078	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.438	0.072	0.238	0.073	0.033	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.381	0.062	0.207	0.064	0.028	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.490	0.080	0.266	0.082	0.036	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.493	0.080	0.267	0.082	0.037	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.505	0.082	0.274	0.084	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.415	0.076	0.252	0.077	0.034	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.361	0.066	0.219	0.067	0.030	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials		0.464	0.084	0.281	0.086	0.038	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.466	0.085	0.282	0.087	0.039	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.479	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.469	0.085	0.284	0.087	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-7. Williamson County VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates		0.392	0.080	0.265	0.081	0.036	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.341	0.069	0.231	0.071	0.032	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2007**	0.438	0.089	0.296	0.091	0.040	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.440	0.089	0.297	0.091	0.041	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.452	0.092	0.305	0.094	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.443	0.090	0.299	0.092	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.369	0.084	0.278	0.085	0.038	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.321	0.073	0.242	0.074	0.033	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2008**	0.412	0.093	0.310	0.096	0.043	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.414	0.094	0.312	0.096	0.043	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.356	0.086	0.285	0.088	0.039	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.310	0.075	0.248	0.076	0.034	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2009**	0.398	0.096	0.319	0.098	0.044	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.400	0.096	0.320	0.099	0.044	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.345	0.088	0.292	0.090	0.040	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.300	0.076	0.254	0.078	0.035	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2010**	0.385	0.098	0.326	0.100	0.045	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.387	0.098	0.328	0.101	0.045	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.301	0.095	0.317	0.097	0.043	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.262	0.083	0.276	0.085	0.038	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2015**	0.337	0.106	0.354	0.109	0.048	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.339	0.107	0.355	0.109	0.049	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.278	0.099	0.330	0.102	0.045	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.242	0.086	0.287	0.088	0.039	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2020**	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.313	0.111	0.370	0.114	0.051	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.278	0.099	0.330	0.102	0.045	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.242	0.086	0.287	0.088	0.039	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2025**	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.313	0.111	0.370	0.114	0.051	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.278	0.099	0.330	0.102	0.045	0.033	0	0	0	0	0	0.026	0.085	0	0	0.002	1.000
Rural Interstates		0.242	0.086	0.287	0.088	0.039	0.057	0	0	0	0	0	0.044	0.148	0	0	0.008	1.000
Urban Arterials	**2030**	0.311	0.111	0.368	0.113	0.050	0.010	0	0	0	0	0	0.008	0.025	0	0	0.003	1.000
Rural Arterials		0.313	0.111	0.370	0.114	0.051	0.008	0	0	0	0	0	0.006	0.022	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-8. Wilson County VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates		0.530	0.049	0.165	0.050	0.022	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates	Wilson	0.463	0.043	0.143	0.044	0.020	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	1998,	0.609	0.057	0.189	0.058	0.026	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials	1999,	0.610	0.057	0.189	0.058	0.026	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local	2000	0.639	0.059	0.198	0.061	0.027	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.627	0.058	0.194	0.060	0.027	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.508	0.053	0.177	0.054	0.024	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.444	0.046	0.154	0.047	0.021	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2001	0.584	0.061	0.204	0.063	0.028	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.585	0.061	0.204	0.063	0.028	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.612	0.064	0.213	0.065	0.029	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.600	0.063	0.209	0.064	0.029	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.486	0.057	0.190	0.058	0.026	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.425	0.050	0.165	0.051	0.023	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2002	0.558	0.066	0.218	0.067	0.030	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.559	0.066	0.218	0.067	0.030	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.585	0.069	0.228	0.070	0.031	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.574	0.067	0.224	0.069	0.031	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.463	0.061	0.203	0.062	0.028	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.405	0.053	0.176	0.054	0.024	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2003	0.533	0.070	0.233	0.072	0.032	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.533	0.070	0.233	0.072	0.032	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.559	0.073	0.244	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.548	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.441	0.065	0.215	0.066	0.029	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.386	0.056	0.187	0.058	0.026	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2004	0.507	0.074	0.247	0.076	0.034	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.508	0.074	0.248	0.076	0.034	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.532	0.078	0.259	0.080	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.522	0.076	0.254	0.078	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.419	0.069	0.228	0.070	0.031	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.366	0.060	0.199	0.061	0.027	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2005	0.482	0.079	0.262	0.081	0.036	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.482	0.079	0.262	0.081	0.036	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.505	0.082	0.274	0.084	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.496	0.081	0.269	0.083	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates		0.397	0.072	0.241	0.074	0.033	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.347	0.063	0.210	0.065	0.029	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials	2006	0.456	0.083	0.277	0.085	0.038	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.457	0.083	0.277	0.085	0.038	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.479	0.087	0.290	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.469	0.085	0.284	0.087	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-8. Wilson County VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.375	0.076	0.254	0.078	0.035	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.328	0.066	0.221	0.068	0.030	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.431	0.087	0.291	0.090	0.040	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.431	0.088	0.292	0.090	0.040	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.452	0.092	0.305	0.094	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.443	0.090	0.299	0.092	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.352	0.080	0.266	0.082	0.036	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.308	0.070	0.232	0.071	0.032	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.405	0.092	0.306	0.094	0.042	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.406	0.092	0.306	0.094	0.042	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.340	0.082	0.273	0.084	0.037	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.298	0.071	0.238	0.073	0.033	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.391	0.094	0.314	0.097	0.043	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.392	0.094	0.314	0.097	0.043	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.329	0.084	0.280	0.086	0.038	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.288	0.073	0.243	0.075	0.033	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.379	0.096	0.321	0.099	0.044	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.379	0.097	0.321	0.099	0.044	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.288	0.091	0.303	0.093	0.042	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.252	0.079	0.264	0.081	0.036	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.331	0.105	0.348	0.107	0.048	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.331	0.105	0.349	0.107	0.048	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.266	0.095	0.316	0.097	0.043	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.233	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.266	0.095	0.316	0.097	0.043	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.233	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.266	0.095	0.316	0.097	0.043	0.042	0	0	0	0	0	0.032	0.107	0	0	0.002	1.000
Rural Interstates		0.233	0.083	0.275	0.085	0.038	0.064	0	0	0	0	0	0.050	0.165	0	0	0.008	1.000
Urban Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.035	0	0	0.003	1.000
Rural Arterials		0.306	0.109	0.363	0.112	0.050	0.013	0	0	0	0	0	0.010	0.032	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-9. "Sullivan +" VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	Sullivan +: 1998, 1999, 2000	0.461	0.060	0.201	0.062	0.027	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.411	0.054	0.179	0.055	0.024	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.538	0.070	0.234	0.072	0.032	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.531	0.069	0.231	0.071	0.032	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.559	0.073	0.243	0.075	0.033	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.549	0.072	0.239	0.073	0.033	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.447	0.063	0.209	0.064	0.029	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.398	0.056	0.186	0.057	0.025	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.522	0.073	0.244	0.075	0.033	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.515	0.072	0.240	0.074	0.033	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.543	0.076	0.253	0.078	0.035	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.532	0.074	0.248	0.076	0.034	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.434	0.065	0.217	0.067	0.030	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.386	0.058	0.193	0.059	0.026	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.506	0.076	0.253	0.078	0.035	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.499	0.075	0.250	0.077	0.034	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.526	0.079	0.263	0.081	0.036	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.516	0.077	0.257	0.079	0.035	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.420	0.068	0.225	0.069	0.031	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.374	0.060	0.200	0.062	0.027	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.490	0.079	0.262	0.081	0.036	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.483	0.078	0.259	0.080	0.035	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.509	0.082	0.272	0.084	0.037	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.499	0.080	0.267	0.082	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.406	0.070	0.233	0.072	0.032	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.361	0.062	0.207	0.064	0.028	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.474	0.082	0.271	0.083	0.037	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.467	0.080	0.268	0.082	0.037	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.492	0.085	0.282	0.087	0.039	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.483	0.083	0.276	0.085	0.038	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.392	0.072	0.241	0.074	0.033	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.349	0.064	0.214	0.066	0.029	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.458	0.084	0.281	0.086	0.038	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.451	0.083	0.277	0.085	0.038	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.475	0.088	0.291	0.090	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.466	0.086	0.286	0.088	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.378	0.075	0.249	0.076	0.034	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.337	0.067	0.221	0.068	0.030	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.441	0.087	0.290	0.089	0.040	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.436	0.086	0.286	0.088	0.039	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.459	0.090	0.301	0.093	0.041	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.450	0.089	0.295	0.091	0.040	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-9. "Sullivan +" VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	**2007**	0.364	0.077	0.257	0.079	0.035	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.324	0.069	0.228	0.070	0.031	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.425	0.090	0.299	0.092	0.041	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.420	0.089	0.295	0.091	0.040	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.442	0.093	0.311	0.096	0.043	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.433	0.092	0.305	0.094	0.042	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2008**	0.350	0.079	0.265	0.081	0.036	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.312	0.071	0.236	0.072	0.032	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.409	0.093	0.308	0.095	0.042	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.404	0.091	0.304	0.094	0.042	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2009**	0.338	0.082	0.271	0.083	0.037	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.301	0.073	0.242	0.074	0.033	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.395	0.095	0.316	0.097	0.043	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.390	0.094	0.312	0.096	0.043	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2010**	0.327	0.083	0.278	0.085	0.038	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.292	0.074	0.247	0.076	0.034	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.382	0.097	0.324	0.100	0.044	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.377	0.096	0.320	0.098	0.044	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2015**	0.286	0.090	0.301	0.093	0.041	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.255	0.081	0.268	0.082	0.037	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.334	0.105	0.351	0.108	0.048	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.330	0.104	0.347	0.107	0.047	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2020**	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2025**	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	**2030**	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-10. "All Other Counties" VMT Mix

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	All Other Counties: 1998, 1999, 2000	0.419	0.068	0.225	0.069	0.031	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.373	0.060	0.201	0.062	0.027	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.489	0.079	0.263	0.081	0.036	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.482	0.078	0.259	0.080	0.036	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.508	0.082	0.273	0.084	0.037	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.498	0.080	0.268	0.082	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2001	0.410	0.069	0.230	0.071	0.032	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.365	0.062	0.205	0.063	0.028	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.479	0.081	0.268	0.083	0.037	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.472	0.080	0.265	0.082	0.036	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.498	0.084	0.279	0.086	0.038	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.488	0.082	0.273	0.084	0.037	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2002	0.402	0.071	0.235	0.072	0.032	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.358	0.063	0.209	0.064	0.029	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.469	0.082	0.274	0.084	0.038	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.463	0.081	0.271	0.083	0.037	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.487	0.086	0.285	0.088	0.039	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.478	0.084	0.279	0.086	0.038	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2003	0.393	0.072	0.240	0.074	0.033	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.350	0.064	0.214	0.066	0.029	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.459	0.084	0.280	0.086	0.038	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.453	0.083	0.276	0.085	0.038	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.477	0.087	0.291	0.089	0.040	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.468	0.086	0.285	0.088	0.039	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2004	0.385	0.074	0.245	0.075	0.034	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.342	0.066	0.218	0.067	0.030	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.449	0.086	0.286	0.088	0.039	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.443	0.085	0.282	0.087	0.039	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.466	0.089	0.297	0.091	0.041	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.458	0.087	0.291	0.089	0.040	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2005	0.376	0.075	0.250	0.077	0.034	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.335	0.067	0.222	0.068	0.030	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.439	0.087	0.291	0.090	0.040	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.433	0.086	0.287	0.088	0.039	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.456	0.091	0.302	0.093	0.041	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.447	0.089	0.297	0.091	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2006	0.367	0.077	0.255	0.078	0.035	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.327	0.068	0.227	0.070	0.031	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.429	0.089	0.297	0.091	0.041	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.423	0.088	0.293	0.090	0.040	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.446	0.093	0.308	0.095	0.042	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.437	0.091	0.302	0.093	0.041	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

Table B.1-10. "All Other Counties" VMT Mix (continued)

Roadway	Year	LDV	LDT1	LDT2	LDT3	LDT4	HDV2B	HDV3	HDV4	HDV5	HDV6	HDV7	HDV8A	HDV8B	HDBS	HDBT	MC	TOTAL
Urban Interstates	2007	0.359	0.078	0.260	0.080	0.036	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.320	0.069	0.231	0.071	0.032	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.419	0.091	0.303	0.093	0.041	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.413	0.090	0.299	0.092	0.041	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.435	0.094	0.314	0.097	0.043	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.427	0.093	0.308	0.095	0.042	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2008	0.350	0.079	0.265	0.081	0.036	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.312	0.071	0.236	0.072	0.032	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.409	0.093	0.308	0.095	0.042	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.404	0.091	0.304	0.094	0.042	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.425	0.096	0.320	0.099	0.044	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.417	0.094	0.314	0.097	0.043	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2009	0.338	0.082	0.271	0.083	0.037	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.301	0.073	0.242	0.074	0.033	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.395	0.095	0.316	0.097	0.043	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.390	0.094	0.312	0.096	0.043	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.411	0.099	0.329	0.101	0.045	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.403	0.097	0.322	0.099	0.044	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2010	0.327	0.083	0.278	0.085	0.038	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.292	0.074	0.247	0.076	0.034	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.382	0.097	0.324	0.100	0.044	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.377	0.096	0.320	0.098	0.044	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.397	0.101	0.336	0.103	0.046	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.390	0.099	0.330	0.101	0.045	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2015	0.286	0.090	0.301	0.093	0.041	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.255	0.081	0.268	0.082	0.037	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.334	0.105	0.351	0.108	0.048	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.330	0.104	0.347	0.107	0.047	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.347	0.110	0.365	0.112	0.050	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.341	0.107	0.358	0.110	0.049	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2020	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2025	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000
Urban Interstates	2030	0.264	0.094	0.314	0.097	0.043	0.043	0	0	0	0	0	0.033	0.110	0	0	0.002	1.000
Rural Interstates		0.235	0.084	0.279	0.086	0.038	0.062	0	0	0	0	0	0.048	0.159	0	0	0.008	1.000
Urban Arterials		0.309	0.110	0.366	0.113	0.050	0.011	0	0	0	0	0	0.009	0.030	0	0	0.003	1.000
Rural Arterials		0.304	0.109	0.361	0.111	0.049	0.014	0	0	0	0	0	0.011	0.036	0	0	0.005	1.000
Urban Local		0.321	0.114	0.380	0.117	0.052	0.003	0	0	0	0	0	0.003	0.008	0	0	0.002	1.000
Rural Local		0.315	0.112	0.373	0.115	0.051	0.008	0	0	0	0	0	0.006	0.019	0	0	0.002	1.000

APPENDIX B.2

DEVELOPMENT OF VEHICLE SPEEDS FOR EMISSIONS MODELING

Development of Vehicle Speeds for Emissions Modeling

Introduction

Mobile source emissions vary considerably for different vehicle speeds. As a result, accurate vehicle data is needed in order to calculate emissions with the MOBILE model. Vehicle speeds are generally different for different types of roadway facilities and for urban vs. rural areas. Guidance for determining vehicle speeds for use in emissions modeling are published in two EPA documents: Procedures for Emission Inventory Preparation, Vol. IV, Mobile Sources (EPA-450/4-81-026) and Use of Locality Specific Transportation Data for the Development of Mobile Source Emission Inventories, (An EPA EIIP Emission Inventory Improvement Program Report; September, 1996). The first report offers several default speed profiles that can be used if more reliable local data are not available. The second report describes special speed studies that can be performed in order to determine appropriate speeds for modeling emissions. In Tennessee, special studies have been performed in the Memphis, Nashville, and Knoxville Metropolitan Planning Areas. These studies have been evaluated in order to develop vehicle speed inputs for use in modeling emissions for Tennessee counties outside the MPO areas.

Default Speeds

Default vehicle speeds and speeds derived from special studies in Tennessee have been compiled and are summarized in Table B.2-1. Speeds are shown for each of 6 roadway types and for both urban and rural areas. The first row in the table shows a default speed of 19.6 mph for all types of roadways. This speed is the average speed in the FTP, Federal Test Procedure used to measure emissions from vehicles. This speed was originally derived from studies in Los Angeles, California and is supposed to represent the average speed for a typical urban commuter trip. EPA suggests that 19.6 mph can be used for all roadway types, but it clearly underestimates the speeds on many roadways. The NAPAP National Acid Precipitation Study calculated regional emissions from mobile sources using 19.6 mph for all road types in urban areas, 55 mph for rural interstates, and 45 mph for all other rural roads. In the Procedures for Emission Inventory Preparation, Vol. IV, Mobile Sources EPA suggests default speeds for all roadway types ranging from 19.6 mph on local streets, collectors and arterials in urban areas, to 57.3 mph on rural interstates (See Table B.2-1 for details). These default speeds are intended for use only if more accurate data are not available for the local area.

Speed Data for Tennessee Highways

Three MPOs in Tennessee have performed special studies to determine vehicle speeds for use in emission inventory development (Knoxville, Memphis and Nashville). The studies were of two types: transportation modeling studies and floating car travel speed studies. The average speeds determined from these studies for each roadway type are summarized in Table B.2-1.

Transportation Modeling Studies

Transportation modeling studies were performed by all 3 MPOs to predict VMT (vehicles miles of travel) for each roadway type. The types of models used are TDM travel demand models such as MINUTP (the minicomputer version of UTP the Urban Transportation Planning model). TDM models employ the traditional 4-step process consisting of trip generation, trip distribution, mode choice and traffic assignment to predict the traffic volumes on each link in the highway system. From this, VMT and vehicle speeds can be calculated. Appendix C, page 8 of the Memphis Metropolitan Area Long Range Transportation Plan states "Operating vehicle speeds for each forecast year and road type were obtained from the regional travel demand model after processing the speeds through a feedback loop to simulate the speeds as close to operating conditions as possible. This is a preferred approach and was discussed and approved by FHWA prior to use in the air quality model." The resulting speeds predicted for each road type in the Memphis area are shown in Table B.2-1.

The MINUTP transportation demand model was also used to develop the Nashville area plan. Data from the MINUTP model were input to the model PPAQ (Post-Processor for Air Quality). This model was developed by Garmen Associates and is an approved EPA model. According to the Nashville Area 2025 Long-Range Transportation Plan, the PPAQ model was used to calculate average speeds for each roadway type for each hour of the day, based on the predicted volume to capacity ratios for each link. Average speeds predicted for the Nashville area are summarized in Table B.2-1.

Floating Car Travel Speed Studies

In addition to the modeled speeds, two of the MPOs conducted floating car travel speed studies on selected corridors. In floating car studies, the investigators travel selected routes in a vehicle keeping the same speed as surrounding traffic. The measuring vehicle must not pass more cars than passes it. The time and distance traveled are recorded so average speeds can be calculated for the corridor. These studies were performed in the Knoxville and Nashville areas.

Average travel speeds were measured during AM and PM peak hours and off-peak hour periods on 47 different highway segments in the Knoxville area. The results of the travel speeds measurements were grouped by roadway type. Measurements were taken on urban and rural interstates, freeways, arterials, collectors and local streets to establish actual speeds for these roadway types. The average speed for all roads within each type was calculated. The AM and PM peak hour speeds were averaged together to get a composite peak hour speed. Then the composite peak hour speed was averaged with the off-peak hour speed to get an overall average speed. The overall average speeds were then included in the summary of speed results shown in Table B.2-1.

Travel speed studies using a floating car were also conducted in the Nashville area. Speeds were measured during peak hour periods on 19 different facilities. Speeds were measured on urban interstates, urban arterials, urban collectors, and rural arterials. The average speed for all roads within each type was calculated. The AM and PM peak hour speeds were averaged together to get a composite peak hour speed. No measurements were performed during off-peak periods in the Nashville area. The peak hour average speeds were then included in the summary of speed results shown in Table B.2-1.

Combined Speed Results

In the report, Use of Locality Specific Transportation Data for the Development of Mobile Source Emission Inventories, (An EPA EIIP Emission Inventory Improvement Program Report; September, 1996) the EPA recommends the use of locality specific data for emission inventories wherever possible instead of using default values. Therefore the data from the MPO modeling and speed measurement studies were judged to be more reliable than the default values. To obtain a reasonable value to use for other counties in Tennessee, the results of the modeling and speed measurement studies for each roadway type were averaged together. The average speeds thus calculated are shown in Table B.2-1. The highest average speed was calculated for rural interstates at 63.8 mph. Urban interstate speeds averaged 54.9 mph. Speeds uniformly decreased from interstates to arterials to collectors to local streets. The lowest average speed was 20.9 mph for urban local streets. Also shown in the table is the standard deviation of the speeds calculated for each roadway type. The speeds for each roadway type were fairly consistent for both the modeling and travel speed measurement approaches. The standard deviation of the speeds ranged from 1.2 mph for rural interstates to 6.0 mph for urban collectors. The average values for speeds for each roadway type shown in Table B.2-1 were considered to be the best available for use in estimating emissions from mobile sources on Tennessee roadways.

Table B.2-1. Vehicle Speeds For Emissions Modeling by Source.

Rural Areas - All Speeds in Miles Per Hour

Source	**Interstates**	**Prin Arterials or Expressway**	**Min Arterials**	**Maj Collectors**	**Min Collectors**	**Local Streets**
FTP	19.6	19.6	19.6	19.6	19.6	19.6
NAPAP	55.0	45.0	45.0	45.0	45.0	45.0
Default speed in Inventory Guidance	57.3	45.4	39.9	35.1	30.5	30.5
Knox MPO Trans Plan- 1997	**62.5**	**47.5**	**37.5**	**37.5**	**37.5**	**30.0**
Memphis MPO Plan - 2000	**64.0**	**42.9**	**41.0**	**39.2**	**39.2**	**24.3**
Knox Travel Speeds Study	**64.9**	**46.6**	**46.6**	**35.1**	**35.1**	
Nashville Speeds Study		**42.6**	**42.6**			
Average Last 4:	**63.8**	**44.9**	**41.9**	**37.3**	**37.3**	**27.2**
Standard Deviation	1.2	2.5	3.8	2.1	2.1	4.0

Urban Areas - All Speeds in Miles Per Hour

Source	**Interstates**	**Freeways**	**Prin Arterials**	**Minor Arterials**	**Collectors**	**Local Streets**
FTP	19.6	19.6	19.6	19.6	19.6	19.6
NAPAP	19.6	19.6	19.6	19.6	19.6	19.6
Default speed in Inventory Guidance	46.3	43.3	18.9	19.6	19.6	19.6
Knox MPO Trans Plan - 1997	**52.5**	**42.5**	**32.5**	**32.5**	**27.5**	**25.0**
Memphis MPO Plan - 2000	**58.0**	**42.8**	**37.3**	**35.8**	**35.8**	**19.0**
Nashville MPO Plan - 1998	**55.9**		**34.5**	**34.5**		**18.7**
Knox Travel Speeds Study	**55.2**	**51.2**	**30.6**	**30.6**	**21.9**	
Nashville Speeds Study	**52.7**		**32.8**	**32.8**	**31.9**	
Average Last 5:	**54.9**	**45.5**	**33.5**	**33.2**	**29.3**	**20.9**
Standard Deviation	2.3	4.9	2.5	2.0	6.0	3.6

FTP = Federal Test Procedure
NAPAP = National Acid Precipitation Study
*Default Speeds in Procedures For Emission Inventory Preparation, Vol IV Mobile Sources. EPA-450/4-81-026.

APPENDIX C

CLASSIFICATION OF COUNTIES INTO EAST, MIDDLE AND WEST TENNESSEE

Table C1. Classification of Counties into East, Middle and West*

West Tennessee	Middle Tennessee	East Tennessee
1. Benton	1. Bedford	1. Anderson
2. Carroll	2. Cannon	2. Bledsoe
3. Chester	3. Cheatham	3. Blount
4. Crockett	4. Clay	4. Bradley
5. Decatur	*5. Coffee*	*5. Campbell*
6. Dyer	6. Davidson	6. Carter
7. Fayette	7. DeKalb	7. Claiborne
8. Gibson	8. Dickson	8. Cocke
9. Hardeman	9. Fentress	*9. Cumberland*
10. Hardin	10. Franklin	10. Grainger
11. Haywood	11. Giles	11. Greene
12. *Henderson*	12. Grundy	12. Hamblen
13. Henry	13. Hickman	13. Hamilton
14. Lake	14. Houston	14. Hancock
15. Lauderdale	15. Humphreys	15. Hawkins
16. McNairy	16. Jackson	16. Jefferson
17. Madison	17. Lawrence	17. Johnson
18. Obion	18. Lewis	18. Knox
19. Shelby	19. Lincoln	19. Loudon
20. Tipton	20. Macon	20. McMinn
21. Weakley	21. Marshall	21. Marion
	22. Maury	22. Meigs
	23. Montgomery	23. Monroe
	24. Moore	24. Morgan
	25. Overton	25. Polk
	26. Perry	26. Rhea
	27. Picket	*27. Roane*
	28. Putnam	28. Scott
	29. Robertson	29. Sevier
	30. Rutherford	30. Sullivan
	31. Sequatchie	31. Unicoi
	32. Smith	32. Union
	33. Stewart	33. Washington
	34. Sumner	
	35. Trousdale	
	36. Van Buren	
	37. Warren	
	38. Wayne	
	39. White	
	40. Williamson	
	41. Wilson	

* Counties in italics represent counties with interstate traffic more than 50% of total DVMT

APPENDIX D

INPUT PARAMETERS FOR MOBILE6 RUNS

Table D1. Header Section (same for ALL subgroups)

Input Command	Value / Description
MOBILE6 INPUT FILE	Identifies input file as a regular command input file rather than a batch file. Self-sufficient command*.
NO DESC OUTPUT	Prevents reporting in descriptive output format Self-sufficient command*.
DATABASE OUTPUT	Specifies MOBILE6 to report output in database format Self-sufficient command*.
WITH FIELDNAMES	Specifies MOBILE6 to include a header record of field names for the database output Self-sufficient command*.
RUN DATA	Marks end of Header section and beginning of Run Section of a regular command input file. Self-sufficient command*.

* A command by itself - no further information required.

Table D2. Shelby + Subgroup

a. Shelby County: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound. Self-sufficient command*.
NO REFUELING	Exclude refueling (stage II) emission from all output values. Self-sufficient command*.
MIN/MAX TEMPERATURE	Minimum Temperature = 71 F Maximum Temperature = 95 F
ABSOLUTE HUMIDITY	Absolute Humidity = 88 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. UShreg.d (for urban) or RShreg.d (for rural) Shelby specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. Ushelby.spd (for urban) or RShelby.spd (for rural) **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) (Filename: RShelby.spd) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph) (Filename: Ushelby.spd)

* A command by itself - no further information required.

a. Continued.

<table>
<tr><th>Input Command</th><th>Value / Description</th></tr>
<tr><td>VMT BY FACILITY</td><td>Name of the external file that contains the VMT distribution fractions.

Art-only.vmt (Arterial) or
F-only.vmt (Freeway) or
R-only.vmt (Ramps) or
L-only.vmt (Local).

Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.</td></tr>
<tr><td>VMT FRACTIONS</td><td>Shelby County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT)</td></tr>
<tr><td>FUEL RVP</td><td>Average fuel Reid vapor pressure = 7.8</td></tr>
<tr><td>ANTI_TAMP PROG</td><td>19 95 30 22222 22222222 1 11 092 12211112

19 = Program Start Year 2019
95 = First Model Year 1995 - 25-year window; For example 1995 model year in analysis year 2020.
30 = Last Model Year 2030
Next set of 14 values - Vehicle Type subject/not subject to
ATP Inspection (1 = NO, 2 = YES) in the
following order
LDGV, LDGT1, LDGT2, LDGT3, LDGT4,
HDGV2B, HDGV3, HDGV4, HDGV5,
HDGV6, HDGV7, HDGV8A, HDGV8B,
GAS BUS
1 = must be entered, entering ‘2’ will discontinue ATP benefits.
1 = Inspection Frequency -Annual
092 = Compliance Rate 92%
12211112 = Inspections Performed (1 = NO, 2 = YES)
Air Pump System Disablement = NO
Catalyst Removal = YES
Fuel Inlet Restrictor Disablement = YES
Tailpipe Lead Deposit Test = NO
EGR Disablement = NO
Evaporative System Disablement = NO
PVC System Disablement = NO
Missing Gas Cap = YES</td></tr>
<tr><td>I/M DESC FILE</td><td>Name of the external file that contains the I/M program specifications:
IM99-01.d, IM02-15.d, or IM20-30.d</td></tr>
</table>

b. Shelby County: I/M Program "1" Parameters

Input Command	Value / Description*
I/M PROGRAM	1 1984 2030 1 T/O IDLE 1 = 1st I/M Program 1984 = Program Start Year 1984 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only IDLE = Test Type - Idle Test
I/M MODEL YEARS	1 1974 1995 *or* 1 1974 2001 1974 = First Model Year 1974 1995 = Last Model Year 1995 for analysis years 2002 through 2010, 2015, 2020, 2025 and 2030. 2001 = Last Model Year 2001 for analysis years 1999 through 2001
I/M VEHICLES	1 22222 22222222 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	1 17.0 17.0 = Stringency level 17%
I/M COMPLIANCE	1 84.0 *or* 1 92.0 84.0 = Compliance rate of 84% for analysis years 1999 through 2010, and for 2015. 92.0 = Compliance rate of 92% for analysis years 2020, 2025, 2030
I/M WAIVER RATES	1 1.0 1.0 1.0 = waiver rate for pre-1981 model year vehicle 1.0 = waiver rate for 1981 and later model year vehicles
I/M EXEMPTION AGE	1 25 25 = vehicles 25 years and older exempt from I/M
I/M GRACE PERIOD	1 1 1 = 1 year grace period when I/M testing not required

* The first value of "1" in all records refers to the 1st I/M program type.

c. Shelby County: I/M Program "2" Parameters

Input Command	Value / Description*
I/M PROGRAM	2 2002 2030 1 T/O OBD I/M 2 = 2nd I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only OBD I/M= Test Type – Exhaust OBD I/M program
I/M MODEL YEARS	2 1996 2030 1996 = First Model Year 1996 2030 = Last Model Year 2030
I/M VEHICLES	2 22222 22222222 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	2 17.0 17.0 = Stringency level 17%
I/M COMPLIANCE	2 84.0 *or* 2 92.0 84.0 = Compliance rate of 84% for analysis years 1999 through 2010, and for 2015. 92.0 = Compliance rate of 92% for analysis years 2020 2025, 2030
I/M WAIVER RATES	2 1.0 1.0 1.0 = waiver rate for pre-1981 model year vehicle 1.0 = waiver rate for 1981 and later model year vehicles

* The first value of "2" in all records refers to the 2nd I/M program type. I/M Program 2 applies to analysis years 2002 and later.

d. Shelby County: I/M Program "3" Parameters

Input Command	Value / Description*
I/M PROGRAM	3 2002 2030 1 T/O EVAP OBD & GC 3 = 3rd I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only EVAP OBD & GC = Evaporative OBD and Gas cap I/M program
I/M MODEL YEARS	3 1996 2006 1996 = First Model Year 1996 2006 = Last Model Year 2006
I/M VEHICLES	3 22222 11111111 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	3 17.0 17.0 = Stringency level 17%
I/M COMPLIANCE	3 84.0 *or* 3 92.0 84.0 = Compliance rate of 84% for analysis years 1999 through 2010, and for 2015. 92.0 = Compliance rate of 92% for analysis years 2020, 2025, 2030
I/M WAIVER RATES	3 1.0 1.0 1.0 = waiver rate for pre-1981 model year vehicle 1.0 = waiver rate for 1981 and later model year vehicles

* The first value of "3" in all records refers to the 3rd I/M program type. I/M Program 3 applies to analysis years 2002 and later.

e. Shelby County: I/M Program "4" Parameters

Input Command	Value / Description*
I/M PROGRAM	4 2002 2030 1 T/O GC 4 = 4th I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only GC = Gas cap Evaporative I/M program
I/M MODEL YEARS	4 1996 2006 1996 = First Model Year 1996 2006 = Last Model Year 2006
I/M VEHICLES	4 11111 22222222 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	4 17.0 17.0 = Stringency level 17%
I/M COMPLIANCE	4 84.0 *or* 4 92.0 84.0 = Compliance rate of 84% for analysis years 1999 through 2010, and for 2015. 92.0 = Compliance rate of 92% for analysis years 2020, 2025, 2030
I/M WAIVER RATES	4 1.0 1.0 1.0 = waiver rate for pre-1981 model year vehicle 1.0 = waiver rate for 1981 and later model year vehicles

* The first value of "4" in all records refers to the 4th I/M program type. I/M Program 4 applies to analysis years 2002 and later.

f. Shelby County: I/M Program "5" Parameters

Input Command	Value / Description*
I/M PROGRAM	5 2002 2030 1 T/O EVAP OBD & GC 5 = 5th I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only EVAP OBD & GC = Evaporative OBD and Gas cap I/M program
I/M MODEL YEARS	5 2007 2030 2007 = First Model Year 2007 2030 = Last Model Year 2030
I/M VEHICLES	5 22222 22222222 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	5 17.0 17.0 = Stringency level 17%
I/M COMPLIANCE	5 84.0 *or* 5 92.0 84.0 = Compliance rate of 84% for analysis years 1999 through 2010, and for 2015. 92.0 = Compliance rate of 92% for analysis years 2020, 2025, 2030
I/M WAIVER RATES	5 1.0 1.0 1.0 = waiver rate for pre-1981 model year vehicle 1.0 = waiver rate for 1981 and later model year vehicles

* The first value of "5" in all records refers to the 5th I/M program type. I/M Program 5 applies to analysis years 2002 and later.

Filenames: IM99-01.d – for analysis years 1999 through 2001; only IDLE I/M
IM02-15.d – for analysis years 2002 through 2015; IDLE and EVAP OBD & GC
IM20-30.d – for analysis years 2020 through 2030; same as IM02-15.d, but different compliance rate (92%)

Table D3. Shelby + Subgroup – Tipton & Fayette Counties: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values Self-sufficient command*
MIN/MAX TEMPERATURE	Minimum Temperature = 71 F Maximum Temperature = 95 F
ABSOLUTE HUMIDITY	Absolute Humidity = 88 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. **County** / **Urban** / **Rural** Tipton & Fayette / UTipreg.d / RTipreg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **County** / **Urban** / **Rural** Tipton & Fayette / UTip&Fay.spd / RTip&Fay.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 9.0

* A command by itself - no further information required.

Table D4. Davidson + Subgroup

a. Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values Self-sufficient command*
MIN/MAX TEMPERATURE	Minimum Temperature = 66 F Maximum Temperature = 93 F
ABSOLUTE HUMIDITY	Absolute Humidity = 75 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. **County** / **Urban** / **Rural** Davidson UDavreg.d RDavreg.d Rutherford URureg.d. RRureg.d Sumner USumreg.d RSumreg.d Wilson UWnreg.d RWnreg.d Williamson UWilreg.d RWilreg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **County** / **Urban** / **Rural** Davidson UDav.spd RDav.spd Rutherford URu.spd RRu.spd Sumner USum.spd RSum.spd Wilson UWn.spd RWn.spd Williamson UWil.spd RWil.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)

* A command by itself - no further information required.

a. Continued.

Input Command	Value / Description
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 7.8
ANTI_TAMP PROG	95 75 30 22222 11111111 1 11 098 12211112 *or* 95 75 30 22222 11111111 1 11 095 12211112 95 = Program Start Year 1995 75 = First Model Year 1975 30 = Last Model Year 2030 Next set of 14 values - Vehicle Type subject/not subject to ATP Inspection (1 = NO, 2 = YES) in the following order LDGV, LDGT1, LDGT2, LDGT3, LDGT4, HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B, GAS BUS 1 = must be entered, entering '2' will discontinue ATP benefits. 1 = Inspection Frequency -Annual 098 *or* 095 = Compliance Rate of 98% for Davidson County and 95% for other 4 Counties. 12211112 = Inspections Performed (1 = NO, 2 = YES) Air Pump System Disablement = NO Catalyst Removal = YES Fuel Inlet Restrictor Disablement = YES Tailpipe Lead Deposit Test = NO EGR Disablement = NO Evaporative System Disablement = NO PVC System Disablement = NO Missing Gas Cap = YES
I/M DESC FILE	Name of the external file that contains the I/M program specifications **County** — **I/M file name** Davidson — DIM99-01.d *or* DIM02-30.d Rutherford — RIM99-01.d *or* RIM02-30.d Sumner — SIM99-01.d *or* SIM02-30.d Wilson — WnIM9901.d *or* WnIM0230.d Williamson — WIM99-01.d *or* WIM02-30.d

b. I/M Program "1" Parameters

Input Command	Value / Description*
I/M PROGRAM	1 1985 2030 1 T/O IDLE *or* 1 1995 2030 1 T/O IDLE 1 = 1st I/M Program 1985 *or* 1995 = Program Start Year 1985 for Davidson County and 1995 for other 4 Counties 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only IDLE = Test Type - Idle Test
I/M MODEL YEARS	1 1975 2001 *or* 1 1975 1995 1975 = First Model Year 1975 2001 = Last Model Year 2001 for analysis years 1999 through 2001. 1995 = Last Model Year 1995 for analysis years 2002 through 2010, 2015, 2020 and 2030
I/M VEHICLES	1 22222 11111111 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	1 30.0 30.0 = Stringency level 30%
I/M COMPLIANCE	1 98.0 *or* 1 95.0 98.0 = Compliance rate of 98% for Davidson County 95.0 = Compliance rate of 95% for other 4 Counties
I/M WAIVER RATES	1 0.0 0.0 *or* 1 5.0 5.0 0.0 *or* 5.0 = Waiver rate for pre-1981 model year vehicle 0% for Davidson County and 5% for other 4 Counties 0.0 *or* 5.0 = Waiver rate for 1981 and later model year vehicles 0% for Davidson County and 5% for other 4 Counties
I/M EXEMPTION AGE	1 25 25 = vehicles 25 years and older exempt from I/M
I/M GRACE PERIOD	1 1 1 = 1 year grace period when I/M testing not required

* the first value of "1" in all records refers to the 1st I/M program type.

c. I/M Program "2" Parameters

Input Command	Value / Description*
I/M PROGRAM	2 2002 2030 1 T/O OBD I/M 2 = 2nd I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only OBD I/M= Test Type – OBD type I/M
I/M MODEL YEARS	2 1996 2030 1996 = First Model Year 1996 2030 = Last Model Year 2030
I/M VEHICLES	2 22222 11111111 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	2 30.0 30.0 = Stringency level 30%
I/M COMPLIANCE	2 98.0 *or* 2 95.0 98.0 = Compliance rate of 98% for Davidson County 95.0 = Compliance rate of 95% for other 4 Counties
I/M WAIVER RATES	2 0.0 0.0 *or* 2 5.0 5.0 0.0 *or* 5.0 = Waiver rate for pre-1981 model year vehicle 0% for Davidson County and 5% for other 4 Counties 0.0 *or* 5.0 = Waiver rate for 1981 and later model year vehicles 0% for Davidson County and 5% for other 4 Counties

* the first value of "2" in all records refers to the 2nd I/M program type. I/M Program 2 applies to analysis years 2002 and later.

d. I/M Program "3" Parameters

Input Command	Value / Description*
I/M PROGRAM	3 2002 2030 1 T/O EVAP OBD & GC 3 = 3rd I/M Program 2002 = Program Start Year 2002 2030 = Program End Year 2030 1 = Inspection Frequency - Annual T/O = Program Type - Test Only EVAP OBD & GC = Evaporative OBD and Gas cap I/M program
I/M MODEL YEARS	3 1996 2030 1996 = First Model Year 1996 2030 = Last Model Year 2030
I/M VEHICLES	3 22222 11111111 1 Vehicle Types subject/not subject to Inspection (1 = NO, 2 = YES) in the following order: LDGV, LDGT1, LDGT2, LDGT3, LDGT4 HDGV2B, HDGV3, HDGV4, HDGV5, HDGV6, HDGV7, HDGV8A, HDGV8B GAS BUS
I/M STRINGENCY	3 30.0 30.0 = Stringency level 30%
I/M COMPLIANCE	3 98.0 *or* 3 95.0 98.0 = Compliance rate of 98% for Davidson County 95.0 = Compliance rate of 95% for other 4 Counties
I/M WAIVER RATES	3 0.0 0.0 *or* 3 5.0 5.0 0.0 *or* 5.0 = Waiver rate for pre-1981 model year vehicle 0% for Davidson County and 5% for other 4 Counties 0.0 *or* 5.0 = Waiver rate for 1981 and later model year vehicles 0% for Davidson County and 5% for other 4 Counties

* the first value of "3" in all records refers to the 3rd I/M program type. I/M Program 3 applies to analysis years 2002 and later.

Table D5. Hamilton + Subgroup: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values Self-sufficient command*
MIN/MAX TEMPERATURE	Minimum Temperature = 66 F Maximum Temperature = 90 F
ABSOLUTE HUMIDITY	Absolute Humidity = 91 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. **County** / **Urban** / **Rural** Hamilton & Marion / UHareg.d / RHareg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **County** / **Urban** / **Rural** Hamilton & Marion / UHam.spd / RHam.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 9.0

* A command by itself - no further information required.

Table D6. Knox + Subgroup: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values. Self-sufficient command*
MIN/MAX TEMPERATURE	Minimum Temperature = 66 F Maximum Temperature = 90 F
ABSOLUTE HUMIDITY	Absolute Humidity = 91 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. **County** / **Urban** / **Rural** Knox + subgroup (all 7 counties) / UKnreg.d / RKnreg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **County** / **Urban** / **Rural** Knox + subgroup (all 7 counties) / UKnox.spd / RKnox.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 9.0

* A command by itself - no further information required.

Table D7. Sullivan + Subgroup: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values Self-sufficient command*
MIN/MAX TEMPERATURE	Minimum Temperature = 66 F Maximum Temperature = 90 F
ABSOLUTE HUMIDITY	Absolute Humidity = 91 grains/pound
REG DIST	Name of the external file that contains the registration distribution fractions. **County** / **Urban** / **Rural** Sullivan + subgroup (all 5 counties) / USnreg.d / RSnreg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **County** / **Urban** / **Rural** Sullivan + subgroup (all 5 counties) / USn.spd / RSn.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 9.0

* A command by itself - no further information required.

Table D8. All Other Counties Subgroup: Run Section

Input Command	Value / Description
EXPRESS HC AS VOC	Directs model to output exhaust HC as volatile organic compound Self-sufficient command*
NO REFUELING	Exclude refueling (stage II) emission from all output values Self-sufficient command*
MIN/MAX TEMPERATURE	Temperature (deg F) West Middle East Minimum 71 66 66 Maximum 95 93 90
ABSOLUTE HUMIDITY	West Middle East Abs. Humidity (gr/lb) 88 75 91
REG DIST	Name of the external file that contains the registration distribution fractions. **Region Urban Rural** West UWestreg.d RWestreg.d Middle UMidreg.d RMidreg.d East UEastreg.d REastreg.d Area specific registration distribution by age for LDV, LDT1, LDT2, LDT3, and LDT4 and national default distribution for the other 11 vehicles types.
SPEED VMT	Name of the external file that contains the speeds. **Region Urban Rural** West UWest.spd RWest.spd Middle UMiddle.spd RMiddle.spd East UEast.spd REast.spd **Rural:** Interstate = 64 mph Arterial = 41 mph Local = National default speed (12.9 mph) Ramps = Not applicable (assume no ramps in rural part of the county) **Urban:** Interstate = 55 mph Arterial = 33 mph Local = National default speed (12.9 mph) Ramps = National default speed (34.6 mph)

* A command by itself - no further information required.

Table D8. Continued.

Input Command	Value / Description
VMT BY FACILITY	Name of the external file that contains the VMT distribution fractions. Art-only.vmt (Arterial) or F-only.vmt (Freeway) or R-only.vmt (Ramps) or L-only.vmt (Local). Allocate all VMT to various roadway or facility types by vehicle class for both rural and urban.
VMT FRACTIONS	County specific VMT fractions by each of 16 combined vehicle types for rural and urban roadway classification. (From TDOT).
FUEL RVP	Average fuel Reid vapor pressure = 9.0

Table D9. Scenario Section (same for ALL subgroups)

Input Command	Value / Description
SCENARIO REC	Label/Title for each scenario
CALENDAR YEAR	1999 through 2010 every year, 2015,2020,2025 and 2030
EVALUATION MONTH	7 = July 1st of calendar year

APPENDIX E

MOBILE SOURCE EMISSIONS FOR EAST, MIDDLE AND WEST TENNESSEE

Table E1. East Tennessee
a. VOC Emissions (tons/day)

Nº	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Anderson	6.07	5.80	5.54	5.23	4.96	4.54	4.14	3.91	3.76	3.53	3.37	3.20	2.41	1.89	1.72	1.80
2	Bledsoe	0.70	0.67	0.65	0.61	0.59	0.55	0.51	0.48	0.47	0.44	0.42	0.40	0.30	0.24	0.22	0.23
3	Blount	6.67	6.48	6.29	6.03	5.80	5.38	4.97	4.75	4.61	4.38	4.22	4.04	3.16	2.57	2.41	2.58
4	Bradley	7.42	7.13	6.88	6.56	6.28	5.84	5.41	5.15	4.99	4.73	4.54	4.34	3.29	2.60	2.40	2.54
5	Campbell	3.61	3.53	3.44	3.30	3.14	2.89	2.63	2.48	2.39	2.24	2.14	2.04	1.65	1.44	1.36	1.45
6	Carter	3.92	3.75	3.58	3.39	3.23	2.98	2.73	2.59	2.50	2.35	2.25	2.14	1.59	1.22	1.09	1.14
7	Claiborne	2.34	2.26	2.19	2.10	2.02	1.89	1.75	1.68	1.63	1.55	1.49	1.43	1.09	0.86	0.80	0.86
8	Cocke	3.36	3.23	3.12	2.98	2.85	2.66	2.46	2.34	2.28	2.16	2.08	1.99	1.52	1.21	1.12	1.18
9	Cumberlan	4.38	4.30	4.21	4.05	3.87	3.57	3.26	3.09	2.98	2.79	2.68	2.56	2.08	1.83	1.74	1.86
10	Grainger	1.90	1.84	1.79	1.72	1.66	1.56	1.45	1.39	1.36	1.29	1.25	1.20	0.92	0.74	0.69	0.74
11	Greene	6.71	6.51	6.32	6.07	5.85	5.48	5.10	4.88	4.76	4.53	4.38	4.20	3.26	2.62	2.45	2.62
12	Hamblen	4.93	4.75	4.58	4.37	4.20	3.91	3.62	3.45	3.34	3.16	3.04	2.90	2.19	1.73	1.61	1.70
13	Hamilton	25.58	24.65	23.79	22.72	21.75	20.09	18.65	17.68	17.06	16.15	15.46	14.69	11.11	8.99	8.52	9.06
14	Hancock	0.31	0.30	0.29	0.28	0.27	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.15	0.12	0.11	0.12
15	Hawkins	3.70	3.53	3.38	3.20	3.06	2.82	2.58	2.46	2.37	2.24	2.14	2.04	1.52	1.17	1.05	1.09
16	Jefferson	5.33	5.18	5.03	4.81	4.61	4.27	3.94	3.76	3.66	3.48	3.37	3.24	2.57	2.10	1.97	2.11
17	Johnson	1.07	1.03	0.99	0.94	0.90	0.84	0.78	0.74	0.71	0.67	0.65	0.62	0.46	0.36	0.33	0.35
18	Knox	31.81	30.81	29.81	28.45	27.26	25.17	23.16	22.05	21.39	20.28	19.52	18.67	14.54	11.77	10.97	11.69
19	Loudon	4.76	4.60	4.43	4.22	4.02	3.70	3.40	3.23	3.13	2.97	2.86	2.73	2.13	1.72	1.59	1.69
20	McMinn	5.99	5.77	5.58	5.33	5.11	4.76	4.41	4.21	4.09	3.88	3.73	3.57	2.74	2.18	2.02	2.14
21	Marion	4.30	4.18	4.06	3.90	3.74	3.48	3.24	3.09	3.01	2.87	2.77	2.65	2.08	1.72	1.65	1.76
22	Meigs	0.77	0.73	0.70	0.66	0.62	0.57	0.52	0.49	0.47	0.44	0.42	0.40	0.29	0.22	0.20	0.20
23	Monroe	3.26	3.15	3.04	2.91	2.79	2.60	2.41	2.31	2.24	2.13	2.05	1.96	1.50	1.19	1.10	1.17
24	Morgan	1.11	1.06	1.02	0.97	0.93	0.86	0.79	0.75	0.73	0.69	0.66	0.63	0.47	0.36	0.33	0.35
25	Polk	1.45	1.39	1.33	1.26	1.20	1.11	1.03	0.97	0.94	0.88	0.85	0.81	0.60	0.46	0.42	0.44
26	Rhea	2.10	2.01	1.93	1.83	1.75	1.62	1.50	1.42	1.37	1.29	1.24	1.18	0.87	0.68	0.62	0.65
27	Roane	4.01	3.87	3.73	3.54	3.35	3.05	2.75	2.57	2.45	2.27	2.15	2.04	1.59	1.34	1.24	1.29
28	Scott	1.36	1.32	1.28	1.23	1.19	1.11	1.03	0.99	0.96	0.92	0.89	0.85	0.65	0.52	0.49	0.52
29	Sevier	6.24	6.09	5.94	5.70	5.51	5.12	4.74	4.54	4.43	4.22	4.08	3.92	3.10	2.54	2.40	2.58
30	Sullivan	13.91	13.40	12.93	12.33	11.83	10.99	10.12	9.68	9.40	8.90	8.57	8.20	6.26	4.90	4.46	4.73
31	Unicoi	1.48	1.44	1.40	1.34	1.29	1.21	1.12	1.08	1.05	1.00	0.97	0.93	0.72	0.57	0.52	0.56
32	Union	0.80	0.77	0.75	0.71	0.68	0.63	0.58	0.55	0.53	0.50	0.48	0.46	0.36	0.29	0.26	0.28
33	Washingto	8.67	8.37	8.09	7.73	7.43	6.91	6.37	6.10	5.94	5.63	5.43	5.20	3.99	3.14	2.86	3.04
		180.03	173.89	168.07	160.45	153.75	142.42	131.37	125.09	121.25	114.76	110.35	105.39	81.18	65.29	60.71	64.52

b. NO_x Emissions (tons/day)

Nº	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Anderson	10.08	9.76	9.33	8.94	8.36	7.61	7.12	6.57	6.17	5.71	5.32	4.89	3.07	2.13	1.72	1.58
2	Bledsoe	0.67	0.65	0.64	0.62	0.60	0.56	0.53	0.49	0.47	0.45	0.43	0.40	0.29	0.22	0.19	0.18
3	Blount	6.54	6.48	6.39	6.28	6.05	5.60	5.33	4.97	4.77	4.52	4.29	4.04	2.90	2.25	1.99	1.97
4	Bradley	14.90	14.51	13.90	13.35	12.50	11.50	10.85	10.14	9.57	8.91	8.34	7.70	4.86	3.32	2.64	2.42
5	Campbell	14.88	14.54	13.89	13.33	12.40	11.37	10.67	9.94	9.29	8.56	7.93	7.22	4.19	2.70	2.06	1.78
6	Carter	3.55	3.45	3.35	3.24	3.08	2.83	2.67	2.49	2.37	2.24	2.12	1.99	1.41	1.06	0.90	0.86
7	Claiborne	2.23	2.20	2.17	2.13	2.05	1.91	1.83	1.72	1.66	1.58	1.51	1.43	1.04	0.80	0.70	0.69
8	Cocke	8.50	8.28	7.91	7.59	7.08	6.51	6.13	5.74	5.40	5.01	4.68	4.30	2.65	1.76	1.37	1.23
9	Cumberlan	15.60	15.32	14.72	14.19	13.27	12.20	11.48	10.72	10.06	9.30	8.64	7.90	4.69	3.09	2.41	2.13
10	Grainger	1.81	1.80	1.77	1.75	1.69	1.58	1.52	1.43	1.38	1.32	1.26	1.20	0.88	0.68	0.60	0.59
11	Greene	14.47	14.20	13.69	13.24	12.46	11.54	10.94	10.29	9.75	9.11	8.56	7.93	5.06	3.48	2.78	2.56
12	Hamblen	7.02	6.86	6.62	6.41	6.06	5.60	5.30	4.96	4.72	4.42	4.17	3.88	2.58	1.85	1.53	1.44
13	Hamilton	41.94	40.98	39.41	37.98	35.72	32.72	30.90	28.75	27.19	25.37	23.77	21.99	14.21	10.05	8.33	7.88
14	Hancock	0.30	0.29	0.29	0.29	0.28	0.26	0.25	0.23	0.22	0.21	0.20	0.19	0.14	0.11	0.10	0.09
15	Hawkins	3.24	3.16	3.07	2.98	2.84	2.62	2.48	2.31	2.21	2.09	1.99	1.87	1.34	1.01	0.86	0.83
16	Jefferson	15.00	14.71	14.15	13.65	12.80	11.79	11.12	10.41	9.81	9.11	8.51	7.82	4.81	3.23	2.53	2.28
17	Johnson	1.02	1.00	0.98	0.96	0.92	0.85	0.81	0.76	0.73	0.69	0.66	0.62	0.44	0.33	0.29	0.28
18	Knox	54.30	53.22	51.35	49.62	46.74	42.86	40.44	37.67	35.64	33.26	31.19	28.89	18.81	13.39	11.06	10.39
19	Loudon	13.40	13.05	12.47	11.96	11.15	10.21	9.58	8.93	8.38	7.75	7.20	6.60	3.99	2.64	2.05	1.83
20	McMinn	14.90	14.53	13.90	13.35	12.47	11.48	10.82	10.13	9.54	8.87	8.28	7.62	4.71	3.15	2.45	2.21
21	Marion	15.73	15.42	14.79	14.25	13.32	12.29	11.60	10.89	10.24	9.50	8.85	8.11	4.85	3.16	2.41	2.13
22	Meigs	0.74	0.72	0.69	0.67	0.63	0.58	0.55	0.51	0.48	0.45	0.43	0.40	0.28	0.20	0.17	0.16
23	Monroe	5.58	5.46	5.27	5.09	4.80	4.44	4.20	3.94	3.74	3.50	3.29	3.06	2.00	1.40	1.15	1.07
24	Morgan	1.06	1.03	1.01	0.98	0.94	0.87	0.83	0.77	0.74	0.70	0.67	0.63	0.44	0.33	0.29	0.28
25	Polk	1.38	1.35	1.31	1.28	1.22	1.13	1.07	1.00	0.96	0.90	0.86	0.81	0.57	0.43	0.36	0.35
26	Rhea	1.92	1.87	1.83	1.78	1.70	1.58	1.50	1.40	1.34	1.27	1.20	1.13	0.81	0.61	0.52	0.51
27	Roane	12.25	11.85	11.24	10.71	9.90	8.99	8.37	7.72	7.17	6.57	6.05	5.49	3.17	2.05	1.59	1.39
28	Scott	1.30	1.28	1.27	1.25	1.21	1.13	1.08	1.02	0.98	0.94	0.90	0.85	0.62	0.48	0.42	0.42
29	Sevier	8.47	8.39	8.23	8.06	7.71	7.14	6.79	6.36	6.08	5.73	5.42	5.07	3.48	2.60	2.23	2.16
30	Sullivan	17.93	17.52	16.92	16.35	15.43	14.20	13.43	12.57	11.97	11.24	10.62	9.91	6.73	4.89	4.07	3.85
31	Unicoi	1.35	1.34	1.32	1.30	1.25	1.17	1.11	1.05	1.01	0.97	0.93	0.88	0.65	0.51	0.44	0.44
32	Union	0.93	0.92	0.89	0.87	0.83	0.77	0.72	0.67	0.64	0.60	0.57	0.53	0.37	0.28	0.24	0.23
33	Washingto	11.20	10.97	10.61	10.27	9.72	8.95	8.48	7.95	7.58	7.13	6.74	6.30	4.30	3.14	2.62	2.49
		324.21	317.13	305.37	294.69	277.19	254.82	240.50	224.51	212.28	197.99	185.55	171.68	110.35	77.32	63.04	58.69

Table E2. Middle Tennessee

a. VOC Emissions (tons/day)

Nº	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Bedford	2.9684	2.871	2.7823	2.6672	2.572	2.4057	2.2354	2.14081	2.0818	1.977	1.9052	1.822	1.3895	1.1029	1.029	1.09943
2	Cannon	0.93	0.89	0.86	0.82	0.78	0.73	0.67	0.64	0.62	0.59	0.56	0.54	0.40	0.31	0.29	0.30
3	Cheatham	3.37	3.27	3.17	3.04	2.94	2.75	2.55	2.45	2.39	2.28	2.21	2.12	1.65	1.33	1.24	1.32
4	Clay	0.54	0.51	0.49	0.47	0.44	0.41	0.38	0.36	0.35	0.33	0.31	0.30	0.22	0.17	0.15	0.16
5	Coffee	4.35	4.23	4.11	3.92	3.73	3.42	3.10	2.91	2.80	2.60	2.48	2.36	1.87	1.61	1.51	1.60
6	Davidson	32.59	32.03	31.41	30.09	28.83	26.11	24.58	22.74	21.64	20.32	19.11	17.87	12.75	10.55	10.53	11.34
7	DeKalb	1.26	1.21	1.17	1.11	1.07	0.99	0.92	0.88	0.85	0.81	0.77	0.74	0.56	0.44	0.40	0.43
8	Dickson	4.61	4.44	4.28	4.08	3.91	3.64	3.37	3.21	3.11	2.95	2.84	2.71	2.06	1.62	1.50	1.59
9	Fentress	1.23	1.18	1.14	1.09	1.05	0.98	0.90	0.86	0.84	0.79	0.76	0.73	0.55	0.43	0.40	0.42
10	Franklin	2.69	2.55	2.43	2.29	2.18	2.00	1.83	1.73	1.66	1.56	1.48	1.40	1.02	0.77	0.69	0.71
11	Giles	3.49	3.37	3.26	3.12	3.00	2.80	2.60	2.48	2.42	2.30	2.22	2.12	1.63	1.30	1.21	1.28
12	Grundy	1.33	1.27	1.21	1.15	1.10	1.01	0.93	0.88	0.85	0.81	0.77	0.74	0.55	0.43	0.39	0.41
13	Hickman	2.73	2.65	2.57	2.46	2.37	2.21	2.05	1.97	1.92	1.83	1.76	1.69	1.31	1.05	0.98	1.04
14	Houston	0.45	0.43	0.41	0.40	0.38	0.35	0.33	0.31	0.30	0.29	0.28	0.26	0.20	0.16	0.14	0.15
15	Humphreys	2.50	2.42	2.34	2.24	2.16	2.01	1.87	1.79	1.74	1.66	1.60	1.54	1.19	0.95	0.88	0.94
16	Jackson	0.81	0.77	0.74	0.70	0.67	0.62	0.57	0.54	0.52	0.49	0.47	0.45	0.33	0.26	0.23	0.25
17	Lawrence	2.86	2.77	2.68	2.57	2.48	2.32	2.16	2.07	2.01	1.91	1.84	1.76	1.34	1.06	0.99	1.06
18	Lewis	0.61	0.59	0.57	0.55	0.53	0.49	0.46	0.44	0.43	0.40	0.39	0.37	0.28	0.23	0.21	0.22
19	Lincoln	2.51	2.39	2.29	2.17	2.07	1.91	1.76	1.67	1.61	1.51	1.44	1.37	1.01	0.77	0.70	0.74
20	Macon	1.19	1.13	1.08	1.03	0.98	0.91	0.83	0.79	0.76	0.72	0.69	0.65	0.48	0.37	0.34	0.36
21	Marshall	2.80	2.70	2.62	2.51	2.41	2.25	2.09	2.00	1.95	1.85	1.79	1.71	1.31	1.05	0.97	1.04
22	Maury	7.39	7.15	6.92	6.63	6.38	5.96	5.53	5.30	5.15	4.89	4.71	4.51	3.45	2.74	2.55	2.72
23	Montgomery	9.99	9.66	9.36	8.97	8.65	8.09	7.51	7.19	6.99	6.64	6.39	6.11	4.66	3.71	3.47	3.70
24	Moore	0.44	0.42	0.40	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.17	0.13	0.12	0.12
25	Overton	1.72	1.66	1.61	1.54	1.48	1.39	1.29	1.23	1.20	1.14	1.10	1.05	0.80	0.63	0.59	0.63
26	Perry	0.68	0.66	0.65	0.62	0.60	0.56	0.53	0.51	0.49	0.47	0.45	0.44	0.34	0.27	0.25	0.27
27	Picket	0.37	0.35	0.34	0.33	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.18	0.14	0.13	0.14
28	Putnam	5.26	5.16	5.04	4.85	4.64	4.28	3.90	3.69	3.56	3.33	3.19	3.05	2.48	2.17	2.06	2.20
29	Robertson	4.76	4.67	4.58	4.40	4.21	3.89	3.55	3.36	3.25	3.04	2.92	2.79	2.28	2.00	1.90	2.03
30	Rutherford	8.72	8.60	8.46	8.11	7.79	7.08	6.68	6.19	5.91	5.56	5.23	4.89	3.48	2.86	2.86	3.09
31	Sequatchie	1.08	1.05	1.02	0.98	0.95	0.89	0.83	0.80	0.78	0.74	0.72	0.69	0.53	0.43	0.40	0.43
32	Smith	2.16	2.12	2.07	1.98	1.89	1.74	1.58	1.49	1.44	1.35	1.29	1.23	1.00	0.87	0.82	0.87
33	Stewart	0.93	0.89	0.86	0.82	0.78	0.73	0.67	0.64	0.62	0.58	0.56	0.53	0.40	0.31	0.28	0.30
34	Sumner	5.48	5.37	5.25	5.01	4.79	4.34	4.08	3.77	3.58	3.35	3.14	2.92	2.04	1.65	1.64	1.76
35	Trousdale	0.66	0.63	0.60	0.57	0.54	0.50	0.46	0.44	0.42	0.40	0.38	0.36	0.26	0.20	0.18	0.19
36	Van Buren	0.50	0.49	0.48	0.46	0.45	0.43	0.40	0.39	0.38	0.36	0.35	0.34	0.27	0.22	0.20	0.22
37	Warren	3.02	2.90	2.78	2.64	2.53	2.35	2.16	2.06	1.99	1.88	1.80	1.71	1.27	0.99	0.91	0.95
38	Wayne	1.16	1.12	1.09	1.04	1.00	0.94	0.87	0.83	0.81	0.77	0.74	0.71	0.54	0.42	0.39	0.42
39	White	1.78	1.72	1.67	1.60	1.55	1.45	1.34	1.29	1.26	1.19	1.15	1.10	0.85	0.67	0.63	0.67
40	Williamson	5.92	5.86	5.77	5.53	5.32	4.83	4.56	4.22	4.03	3.79	3.57	3.34	2.38	1.95	1.95	2.11
41	Wilson	5.14	5.06	4.96	4.73	4.53	4.10	3.86	3.57	3.40	3.19	3.00	2.80	1.98	1.62	1.61	1.73
		142.97	139.22	135.54	129.67	124.40	114.50	106.59	100.40	96.63	91.15	86.87	82.28	61.43	49.94	47.75	51.05

b. NO_x Emissions (tons/day)

Nº	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Bedford	2.82	2.79	2.75	2.70	2.61	2.44	2.34	2.20	2.12	2.02	1.93	1.83	1.34	1.03	0.91	0.89
2	Cannon	0.89	0.87	0.85	0.84	0.80	0.75	0.71	0.67	0.64	0.61	0.58	0.55	0.39	0.30	0.26	0.25
3	Cheatham	8.83	8.67	8.35	8.06	7.58	7.02	6.65	6.25	5.92	5.52	5.18	4.78	3.00	2.03	1.60	1.45
4	Clay	0.51	0.50	0.49	0.48	0.46	0.42	0.40	0.37	0.36	0.34	0.32	0.30	0.21	0.16	0.14	0.13
5	Coffee	13.98	13.63	13.02	12.49	11.62	10.63	9.95	9.24	8.63	7.94	7.35	6.70	3.95	2.61	2.04	1.80
6	Davidson	79.67	78.43	75.97	73.08	68.98	62.95	59.41	54.77	51.44	47.59	44.05	40.18	23.42	14.95	11.78	10.88
7	DeKalb	1.20	1.18	1.16	1.14	1.09	1.02	0.97	0.91	0.88	0.83	0.79	0.75	0.54	0.42	0.36	0.35
8	Dickson	9.47	9.24	8.86	8.53	8.00	7.37	6.96	6.52	6.15	5.73	5.37	4.96	3.15	2.16	1.72	1.58
9	Fentress	1.18	1.16	1.14	1.11	1.07	1.00	0.96	0.90	0.86	0.82	0.78	0.74	0.54	0.41	0.36	0.35
10	Franklin	2.47	2.40	2.32	2.25	2.14	1.97	1.87	1.73	1.65	1.56	1.47	1.38	0.97	0.72	0.61	0.58
11	Giles	7.79	7.62	7.33	7.07	6.64	6.14	5.81	5.45	5.16	4.81	4.51	4.17	2.65	1.81	1.44	1.32
12	Grundy	3.35	3.24	3.08	2.94	2.73	2.50	2.34	2.18	2.04	1.89	1.75	1.61	0.98	0.64	0.49	0.44
13	Hickman	7.14	7.00	6.72	6.49	6.09	5.63	5.32	5.00	4.73	4.40	4.13	3.81	2.38	1.61	1.26	1.14
14	Houston	0.43	0.42	0.41	0.40	0.39	0.36	0.35	0.32	0.31	0.30	0.28	0.27	0.19	0.15	0.13	0.13
15	Humphreys	6.58	6.44	6.19	5.96	5.59	5.16	4.88	4.58	4.33	4.03	3.77	3.48	2.17	1.46	1.14	1.03
16	Jackson	0.77	0.75	0.73	0.72	0.69	0.64	0.60	0.56	0.54	0.51	0.49	0.46	0.33	0.25	0.21	0.21
17	Lawrence	2.60	2.57	2.54	2.50	2.42	2.27	2.17	2.05	1.98	1.89	1.81	1.72	1.27	0.98	0.87	0.86
18	Lewis	0.58	0.58	0.57	0.56	0.54	0.50	0.48	0.45	0.44	0.42	0.40	0.38	0.28	0.21	0.19	0.19
19	Lincoln	2.28	2.23	2.17	2.11	2.02	1.87	1.78	1.65	1.58	1.50	1.42	1.34	0.95	0.72	0.62	0.60
20	Macon	1.13	1.11	1.08	1.05	1.00	0.93	0.88	0.82	0.79	0.74	0.71	0.67	0.47	0.36	0.31	0.30
21	Marshall	5.42	5.31	5.13	4.96	4.68	4.33	4.11	3.86	3.66	3.42	3.22	2.99	1.94	1.35	1.09	1.02
22	Maury	11.51	11.31	10.96	10.64	10.08	9.35	8.88	8.34	7.95	7.47	7.05	6.58	4.40	3.16	2.62	2.48
23	Montgomery	12.57	12.38	12.05	11.75	11.20	10.40	9.92	9.32	8.92	8.42	7.99	7.50	5.20	3.84	3.26	3.14
24	Moore	0.42	0.41	0.40	0.39	0.37	0.34	0.32	0.30	0.29	0.27	0.26	0.24	0.17	0.13	0.11	0.10
25	Overton	1.64	1.62	1.60	1.57	1.52	1.42	1.36	1.28	1.24	1.18	1.13	1.07	0.78	0.60	0.53	0.52
26	Perry	0.65	0.65	0.64	0.64	0.62	0.58	0.56	0.52	0.51	0.49	0.47	0.44	0.33	0.26	0.23	0.22
27	Picket	0.35	0.35	0.34	0.34	0.33	0.31	0.30	0.28	0.27	0.26	0.25	0.24	0.17	0.14	0.12	0.12
28	Putnam	18.84	18.50	17.77	17.13	16.02	14.73	13.86	12.94	12.14	11.22	10.43	9.54	5.67	3.75	2.94	2.60
29	Robertson	18.22	17.90	17.21	16.60	15.53	14.30	13.47	12.59	11.81	10.92	10.15	9.28	5.50	3.62	2.82	2.48
30	Rutherford	25.77	25.46	24.72	23.84	22.53	20.70	19.57	18.17	17.07	15.80	14.64	13.34	7.63	4.71	3.56	3.17
31	Sequatchie	1.03	1.02	1.01	1.00	0.97	0.91	0.88	0.83	0.80	0.77	0.74	0.70	0.52	0.41	0.36	0.36
32	Smith	8.98	8.79	8.41	8.08	7.53	6.91	6.49	6.05	5.66	5.22	4.84	4.41	2.58	1.67	1.28	1.11
33	Stewart	0.89	0.87	0.85	0.84	0.80	0.74	0.71	0.66	0.64	0.60	0.57	0.54	0.39	0.30	0.26	0.25
34	Sumner	13.03	12.82	12.44	11.95	11.29	10.31	9.72	8.96	8.40	7.76	7.17	6.53	3.72	2.31	1.77	1.61
35	Trousdale	0.63	0.62	0.60	0.58	0.56	0.52	0.49	0.45	0.43	0.41	0.39	0.37	0.26	0.19	0.16	0.16
36	Van Buren	0.48	0.48	0.48	0.47	0.46	0.44	0.42	0.40	0.39	0.38	0.36	0.35	0.26	0.21	0.18	0.18
37	Warren	2.72	2.67	2.61	2.55	2.45	2.27	2.17	2.02	1.94	1.84	1.75	1.66	1.19	0.91	0.79	0.77
38	Wayne	1.11	1.10	1.08	1.06	1.03	0.96	0.92	0.86	0.83	0.79	0.76	0.72	0.52	0.40	0.35	0.35
39	White	1.70	1.68	1.66	1.64	1.58	1.48	1.42	1.34	1.29	1.23	1.18	1.12	0.83	0.64	0.56	0.56
40	Williamson	16.14	15.97	15.55	15.02	14.24	13.08	12.38	11.48	10.80	10.01	9.28	8.47	4.88	3.05	2.34	2.11
41	Wilson	16.85	16.56	15.99	15.35	14.42	13.19	12.44	11.52	10.79	9.96	9.20	8.36	4.72	2.87	2.13	1.86
		312.63	307.30	297.23	286.88	270.69	248.83	235.23	218.82	206.39	191.85	178.92	164.52	100.85	67.47	53.88	49.71

Table E3. West Tennessee
a. VOC Emissions (tons/day)

No.	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Benton	2.16	2.08	2.01	1.92	1.84	1.71	1.58	1.51	1.46	1.39	1.34	1.28	0.97	0.76	0.71	0.75
2	Carroll	2.58	2.47	2.37	2.25	2.15	1.99	1.84	1.75	1.69	1.59	1.53	1.45	1.08	0.83	0.76	0.80
3	Chester	1.22	1.17	1.14	1.08	1.04	0.97	0.90	0.86	0.84	0.80	0.77	0.73	0.55	0.44	0.40	0.43
4	Crockett	1.46	1.41	1.36	1.30	1.25	1.16	1.08	1.03	1.00	0.95	0.91	0.87	0.66	0.52	0.48	0.51
5	Decatur	1.57	1.53	1.49	1.43	1.39	1.30	1.21	1.17	1.14	1.09	1.05	1.01	0.79	0.63	0.60	0.64
6	Dyer	3.71	3.55	3.40	3.22	3.07	2.84	2.61	2.48	2.39	2.26	2.16	2.05	1.51	1.17	1.06	1.12
7	Fayette	2.85	2.77	2.69	2.57	2.46	2.26	2.11	1.99	1.92	1.82	1.74	1.65	1.27	1.10	1.09	1.18
8	Gibson	3.79	3.61	3.45	3.27	3.11	2.88	2.64	2.51	2.41	2.27	2.17	2.05	1.50	1.15	1.05	1.09
9	Hardeman	2.25	2.15	2.05	1.95	1.86	1.72	1.58	1.50	1.44	1.36	1.30	1.23	0.90	0.69	0.63	0.66
10	Hardin	2.20	2.12	2.04	1.95	1.87	1.74	1.61	1.54	1.49	1.41	1.35	1.29	0.97	0.76	0.70	0.74
11	Haywood	2.57	2.50	2.43	2.31	2.20	2.01	1.82	1.71	1.64	1.53	1.46	1.39	1.10	0.95	0.89	0.94
12	Henderson	3.33	3.27	3.21	3.09	2.96	2.73	2.49	2.36	2.28	2.14	2.05	1.96	1.60	1.40	1.34	1.43
13	Henry	2.80	2.67	2.56	2.43	2.32	2.15	1.98	1.88	1.82	1.71	1.64	1.56	1.15	0.89	0.81	0.85
14	Lake	0.35	0.33	0.31	0.29	0.27	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.11	0.08	0.07	0.07
15	Lauderdale	2.10	2.00	1.90	1.79	1.70	1.56	1.43	1.35	1.29	1.21	1.15	1.09	0.78	0.59	0.53	0.55
16	Madison	11.19	10.81	10.46	10.00	9.62	8.99	8.33	7.97	7.75	7.36	7.08	6.77	5.15	4.08	3.80	4.06
17	McNairy	2.52	2.43	2.34	2.23	2.14	2.00	1.85	1.76	1.71	1.62	1.56	1.48	1.11	0.87	0.80	0.85
18	Obion	3.27	3.12	2.99	2.82	2.69	2.49	2.28	2.17	2.09	1.96	1.87	1.78	1.30	0.99	0.90	0.94
19	Shelby	44.36	43.18	42.07	40.24	38.54	35.02	32.77	30.59	29.29	27.64	26.19	24.68	18.20	12.39	11.97	12.84
20	Tipton	2.11	2.03	1.96	1.87	1.79	1.63	1.52	1.43	1.37	1.30	1.23	1.16	0.87	0.74	0.73	0.78
21	Weakley	2.49	2.37	2.27	2.15	2.04	1.89	1.74	1.65	1.58	1.49	1.42	1.35	0.99	0.76	0.69	0.72
		100.88	97.57	94.50	90.17	86.31	79.29	73.60	69.40	66.81	63.08	60.15	57.00	42.58	31.79	30.02	31.97

b. NO_x Emissions (tons/day)

No.	County	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
1	Benton	4.84	4.72	4.52	4.35	4.08	3.76	3.55	3.32	3.13	2.92	2.73	2.52	1.57	1.06	0.84	0.76
2	Carroll	2.55	2.49	2.43	2.37	2.26	2.09	1.99	1.86	1.78	1.68	1.59	1.50	1.05	0.79	0.67	0.65
3	Chester	1.11	1.10	1.08	1.06	1.03	0.96	0.92	0.86	0.83	0.79	0.76	0.72	0.52	0.40	0.35	0.35
4	Crockett	1.33	1.31	1.29	1.27	1.23	1.14	1.09	1.03	0.99	0.94	0.90	0.85	0.62	0.47	0.42	0.41
5	Decatur	3.60	3.55	3.44	3.34	3.15	2.93	2.78	2.63	2.49	2.33	2.19	2.04	1.30	0.89	0.71	0.66
6	Dyer	4.73	4.61	4.44	4.28	4.04	3.72	3.52	3.28	3.11	2.91	2.74	2.55	1.69	1.21	1.00	0.95
7	Fayette	10.24	10.03	9.63	9.28	8.69	7.99	7.54	7.04	6.60	6.11	5.68	5.18	3.05	1.99	1.54	1.38
8	Gibson	3.30	3.22	3.14	3.06	2.92	2.71	2.57	2.39	2.29	2.16	2.05	1.93	1.37	1.03	0.88	0.86
9	Hardeman	2.00	1.95	1.90	1.86	1.78	1.64	1.56	1.46	1.39	1.32	1.25	1.18	0.84	0.63	0.54	0.52
10	Hardin	1.94	1.92	1.88	1.85	1.78	1.66	1.59	1.49	1.43	1.36	1.30	1.23	0.89	0.68	0.60	0.59
11	Haywood	9.91	9.65	9.19	8.80	8.16	7.46	6.98	6.49	6.05	5.56	5.14	4.67	2.69	1.73	1.31	1.13
12	Henderson	11.70	11.53	11.10	10.74	10.06	9.28	8.76	8.19	7.70	7.13	6.63	6.07	3.62	2.40	1.88	1.66
13	Henry	2.42	2.37	2.32	2.27	2.17	2.02	1.92	1.79	1.72	1.63	1.55	1.46	1.04	0.79	0.68	0.67
14	Lake	0.32	0.31	0.30	0.28	0.27	0.24	0.23	0.21	0.20	0.19	0.17	0.16	0.11	0.08	0.06	0.06
15	Lauderdale	1.82	1.77	1.71	1.66	1.58	1.46	1.38	1.28	1.22	1.15	1.09	1.02	0.71	0.53	0.45	0.43
16	Madison	18.11	17.77	17.17	16.64	15.72	14.56	13.83	12.98	12.33	11.56	10.89	10.13	6.66	4.71	3.86	3.63
17	McNairy	2.30	2.27	2.23	2.19	2.11	1.96	1.88	1.76	1.69	1.61	1.53	1.45	1.05	0.80	0.70	0.69
18	Obion	2.86	2.79	2.72	2.65	2.53	2.34	2.23	2.07	1.98	1.87	1.78	1.67	1.19	0.89	0.76	0.74
19	Shelby	74.83	73.80	71.97	69.79	66.48	60.88	57.67	53.19	50.27	46.83	43.65	40.16	25.04	14.29	11.19	10.36
20	Tipton	2.40	2.37	2.33	2.29	2.21	2.03	1.94	1.78	1.70	1.59	1.50	1.39	0.94	0.72	0.65	0.65
21	Weakley	2.19	2.14	2.09	2.03	1.94	1.80	1.71	1.59	1.52	1.44	1.36	1.28	0.91	0.68	0.58	0.57
		164.51	161.68	156.89	152.04	144.19	132.63	125.61	116.69	110.45	103.07	96.47	89.17	56.86	36.77	29.68	27.70

Table E4. Statewide Emissions

a. VOC Emissions (tons/day)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
East	180.03	173.89	168.07	160.45	153.75	142.42	131.37	125.09	121.25	114.76	110.35	105.39	81.18	65.29	60.71	64.52
Middle	142.97	139.22	135.54	129.67	124.40	114.50	106.59	100.40	96.63	91.15	86.87	82.28	61.43	49.94	47.75	51.05
West	100.88	97.57	94.50	90.17	86.31	79.29	73.60	69.40	66.81	63.08	60.15	57.00	42.58	31.79	30.02	31.97
TOTAL	423.89	410.69	398.11	380.29	364.46	336.21	311.55	294.89	284.69	269.00	257.38	244.66	185.19	147.01	138.48	147.54

b. NO_x Emissions (tons/day)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2015	2020	2025	2030
East	324.21	317.13	305.37	294.69	277.19	254.82	240.50	224.51	212.28	197.99	185.55	171.68	110.35	77.32	63.04	58.69
Middle	312.63	307.30	297.23	286.88	270.69	248.83	235.23	218.82	206.39	191.85	178.92	164.52	100.85	67.47	53.88	49.71
West	164.51	161.68	156.89	152.04	144.19	132.63	125.61	116.69	110.45	103.07	96.47	89.17	56.86	36.77	29.68	27.70
TOTAL	801.35	786.11	759.48	733.62	692.07	636.29	601.34	560.02	529.11	492.91	460.94	425.37	268.05	181.56	146.60	136.10

11TH TECHNICAL MEETING OF THE AR-TN-MS OZONE STUDY (ATMOS)

12-13 February 2004
Memphis, Tennessee

Presented to the
ATMOS Technical Committee

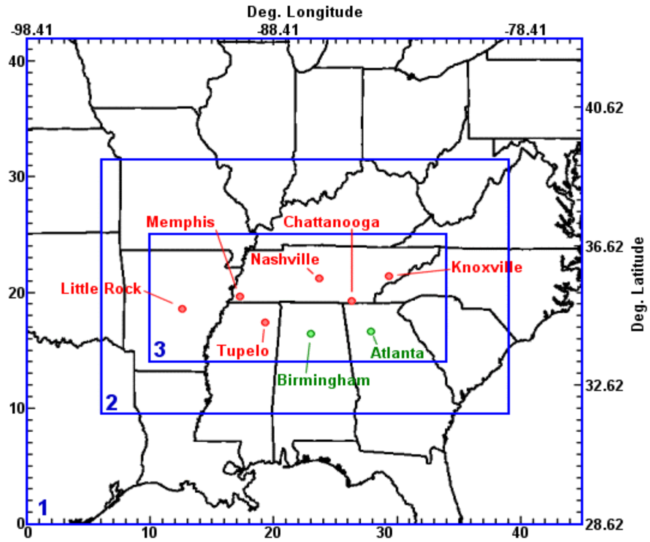
Presented by
Sharon Douglas & Jay Haney
Systems Applications International (SAI)
San Rafael, CA

ICF CONSULTING

THIS PRESENTATION

- Emission inventory updates (for 2001 and 2007)
- Overview of the third modeling episode (ADEQ July 2002 simulation period)
- Future-year baseline simulation results
- Control-strategy simulation results
- Attainment test and weight of evidence

ATMOS UAM-V5 MODELING



Grid 1: (-98.41,28.62) – 45x42 – 36-km Cells
Grid 2: (-95.41, 31.79) – 99x66 – 12-km Cells
Grid 3: (-93.41, 33.29) – 216x99 – 4-km Cells

ATMOS/EAC SIMULATION PERIODS

- 29 August – 9 September 1999 — ATMOS Episode
- 16-22 June 2001 — ATMOS/EAC Episode
- 4-10 July 2002 — ADEQ Episode

UPDATES TO THE 2001 CURRENT-YEAR EMISSION INVENTORY

- Incorporated new (actual) emission estimates for Tennessee gas compressor station sources
- Included new point source data for selected sources for Shelby County (minor updates)
- Incorporated corrections to stack parameters for various Tennessee point sources

REVISED ATMOS/EAC FUTURE-YEAR (2007) BASELINE EMISSIONS

- Mobile Sources
  - Tennessee VMT: used either 12-yr VMT trend (1990-2002) or 5-yr VMT trend (1998-2002) to estimate 2007 VMT
  - Georgia 2007 VMT: incorporated new future year estimates for the entire state (provided by GDNR)

2007 VMT ESTIMATES FOR TENNESSEE COUNTIES

- Memphis/Shelby County: 5-yr trend
- Nashville EAC
  - Davidson, Rutherford, Sumner, Williamson, Wilson – avg 5-yr trend and TDM model output
  - Robertson, Cheatham, Dickson – 12-yr trend – TDEC data
- Knoxville EAC: 12-yr trend
- Chattanooga EAC: 12-yr trend
- Tri-Cities EAC: 12-yr trend
- All other TN counties: 12-yr trend

ESTIMATED 2007 VMT FOR SELECTED TENNESSEE COUNTIES USING DIFFERENT GROWTH ASSUMPTIONS

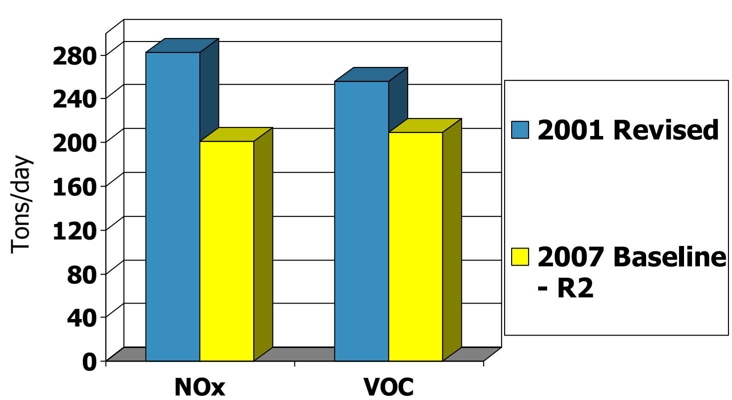
County	90-02 VMT Trend	98-02 VMT Trend	% Diff
Shelby	28646022	26731851	-7
Davidson	24393988	22386667* * TDM-derived	N/A
Knox	15571557	16432593	+6
Hamilton	11662560	10741338	-8
Washington	3306892	2914177	-12
Tennessee	218247678	210369615	-4

REVISED ATMOS/EAC FUTURE-YEAR (2007) BASELINE EMISSIONS

- Point Sources
  - All TVA combustion turbines (CT's) set to operate 4hrs/day (Noon – 4 pm) for three days of each episode
  - Gas compressors – TN – applied 6% growth to base case level emissions and removed two compressors from Tennessee Gas Pipeline Station 87
  - Gas compressor – MS – new emissions for Texas Gas Transmission source in DeSoto Co. received from MDEQ
  - Included revised 2007 estimates for Williams Refining in Shelby County, TN

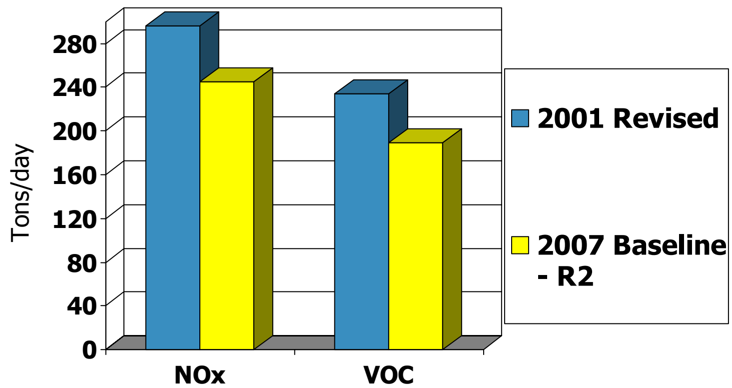
ANTHROPOGENIC EMISSIONS: MEMPHIS EAC AREA

Emissions for 18 June episode day



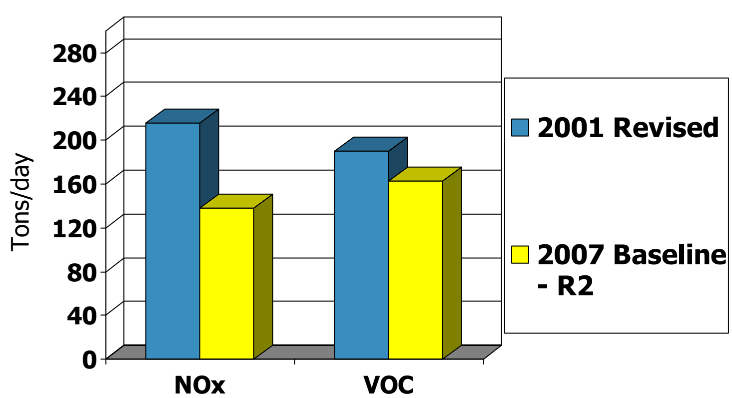
ANTHROPOGENIC EMISSIONS: NASHVILLE EAC AREA

Emissions for 18 June episode day



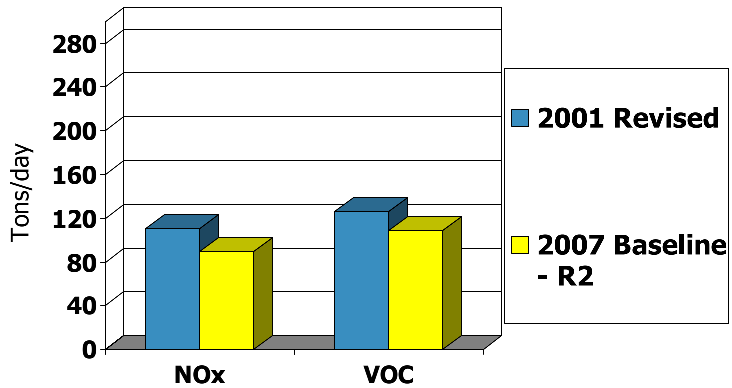
ANTHROPOGENIC EMISSIONS: KNOXVILLE EAC AREA

Emissions for 18 June episode day



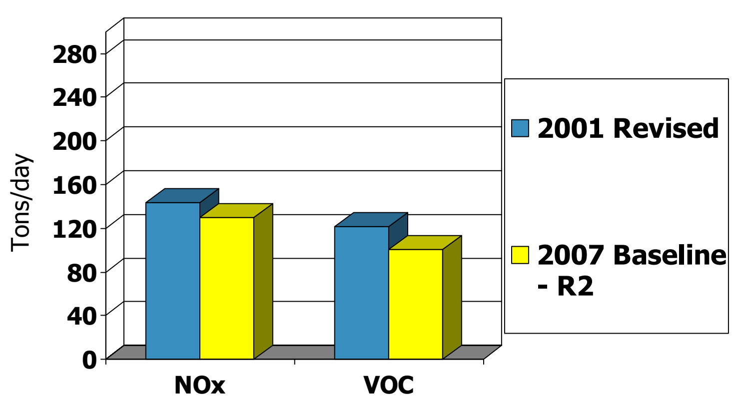
ANTHROPOGENIC EMISSIONS: CHATTANOOGA EAC AREA

Emissions for 18 June episode day

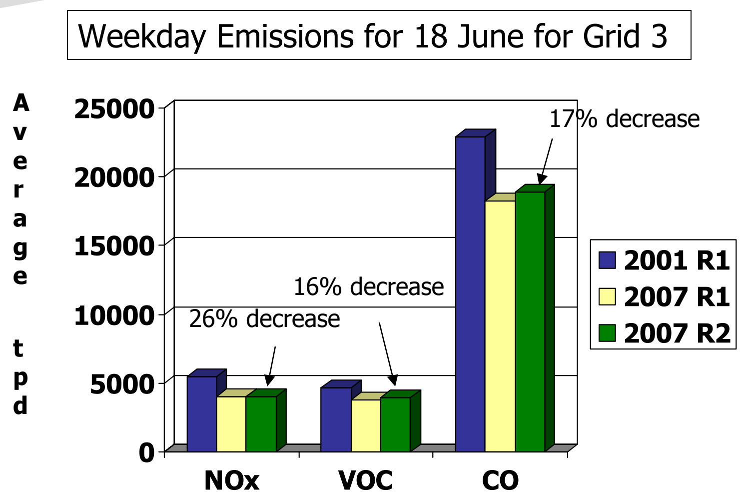


ANTHROPOGENIC EMISSIONS: TRI-CITIES EAC AREA

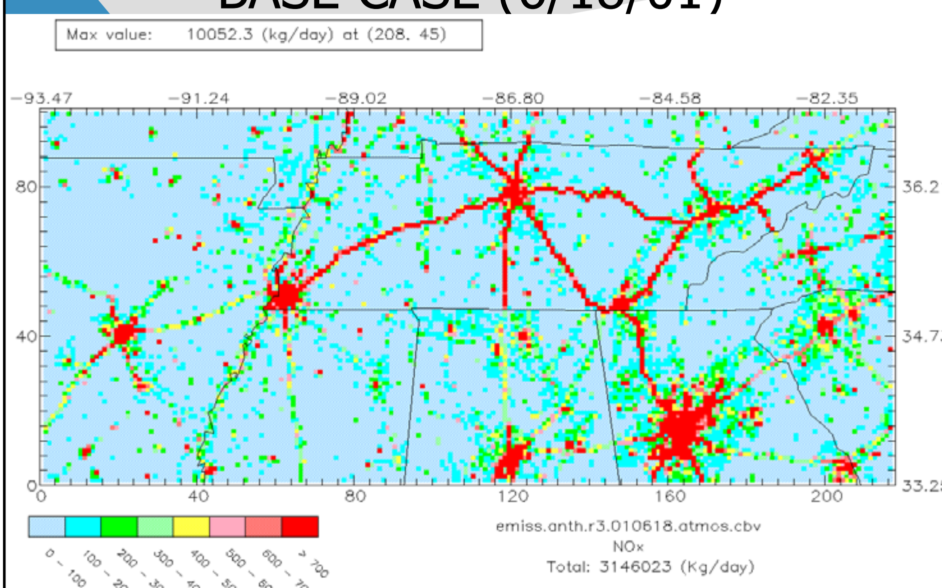
Emissions for 18 June episode day



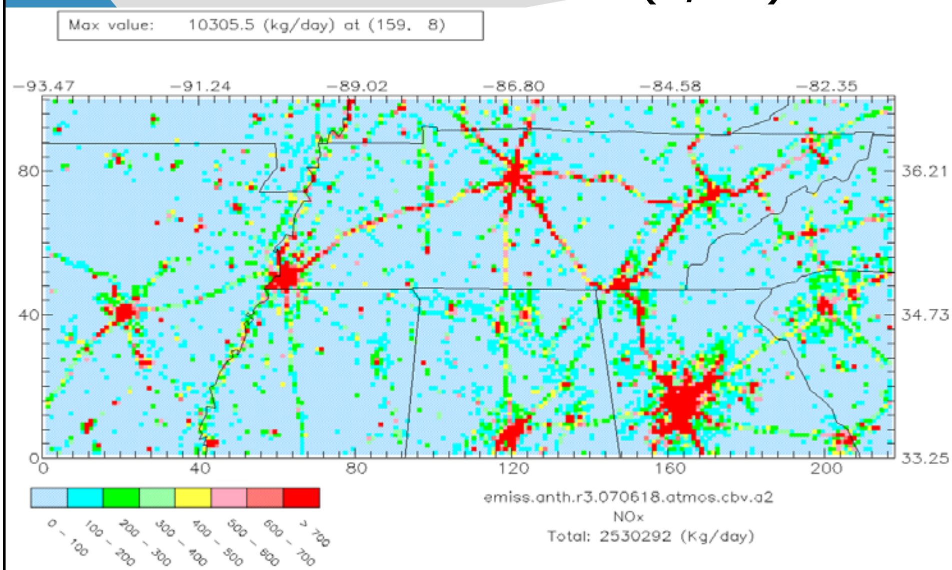
COMPARISON OF NO_x, VOC, & CO: 2001 R1, 2007 R1, & 2007 R2



TOTAL LOW-LEVEL NOX EMISSIONS: BASE CASE (6/18/01)



TOTAL LOW-LEVEL NOX EMISSIONS: 2007 REVISED VMT (6/18)



ADEQ JULY 2002 EPISODE FOR ATMOS EAC ANALYSIS

- Provides an additional multi-day episode to support the ATMOS EAC modeling analysis
  - Includes one or more exceedance days for all EAC areas
  - Provides additional days for representing key met conditions for Memphis, Knoxville, and Chattanooga, and an additional day with new, key met conditions for Nashville
  - Provides additional days for the attainment test application for all areas

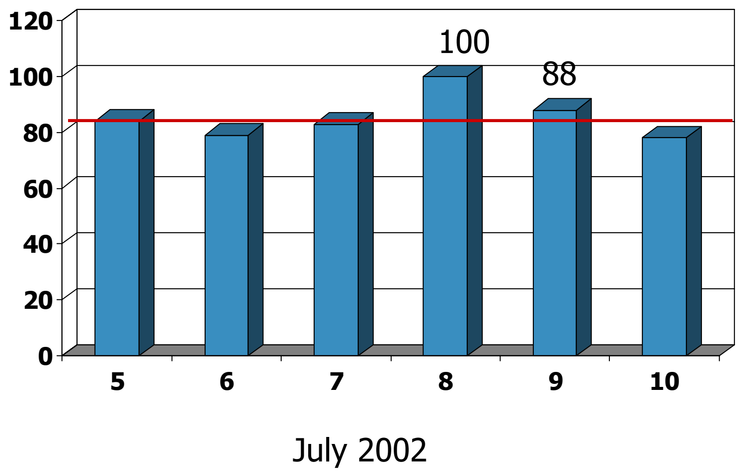
METEOROLOGICAL SUMMARY FOR 4-10 JULY 2002

- Surface weather maps show
  - Little Rock is under the influence of H pressure during this period
  - Some clouds and rain on the 10^{th}
- Pressure patterns aloft show continental high pressure for 4-10 July that weakens throughout the period

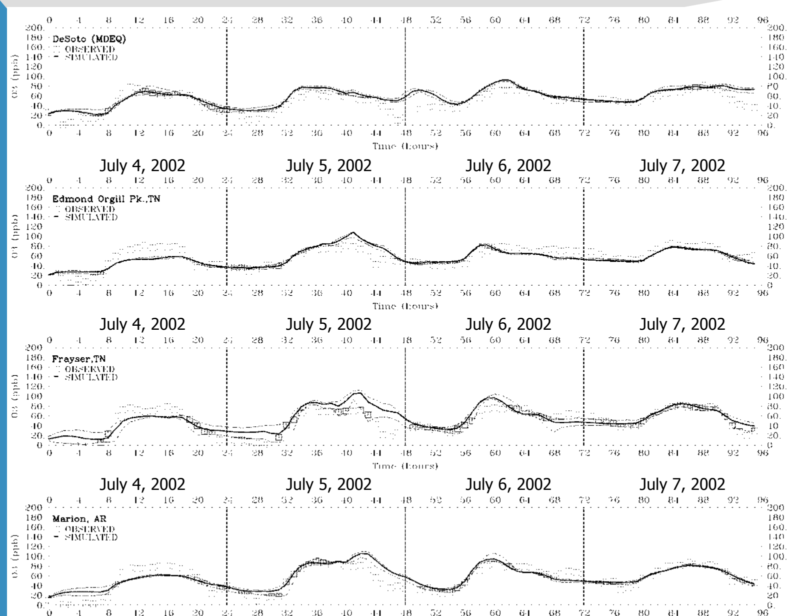
METEOROLOGICAL SUMMARY FOR 4-10 JULY 2002 (CONCLUDED)

- Maximum surface temperatures
  - Low to mid 90s during the entire period
- Winds aloft
  - Easterly through the 6^{th}
  - Then northerly to westerly (and very light) during the higher ozone days

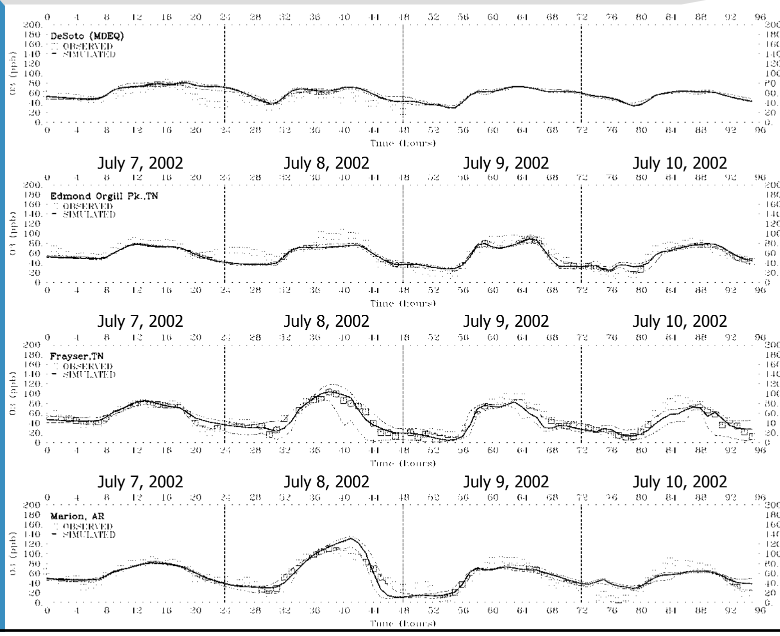
MAXIMUM 8-HOUR OZONE (PPB): MEMPHIS



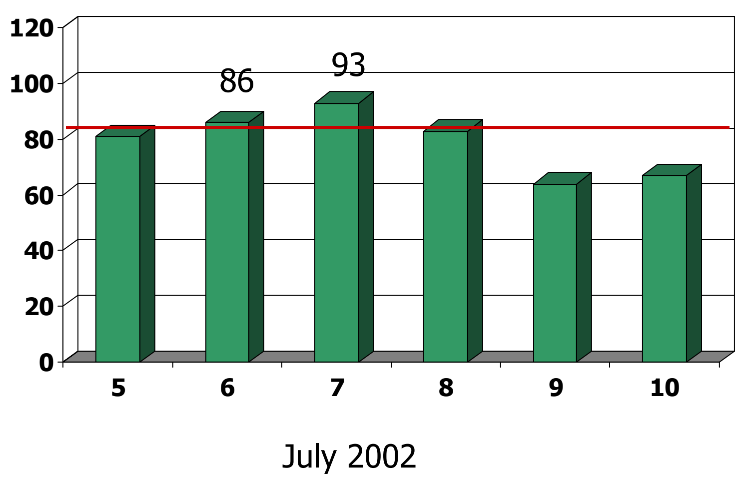
MEMPHIS: JULY 4-7



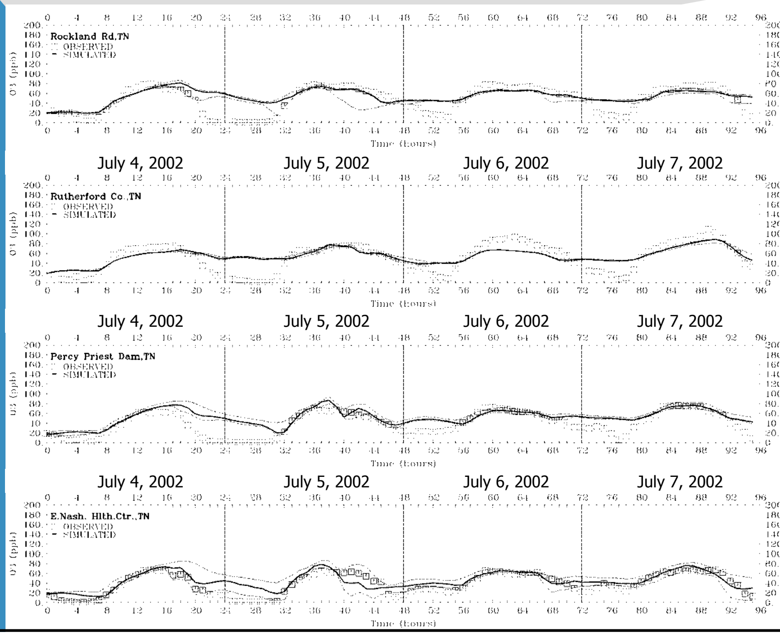
MEMPHIS: JULY 7-10



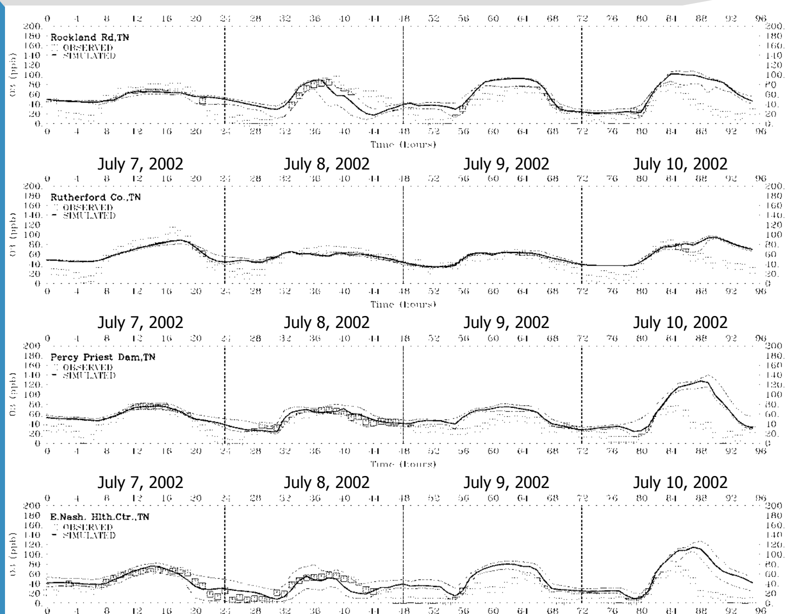
MAXIMUM 8-HOUR OZONE (PPB): NASHVILLE



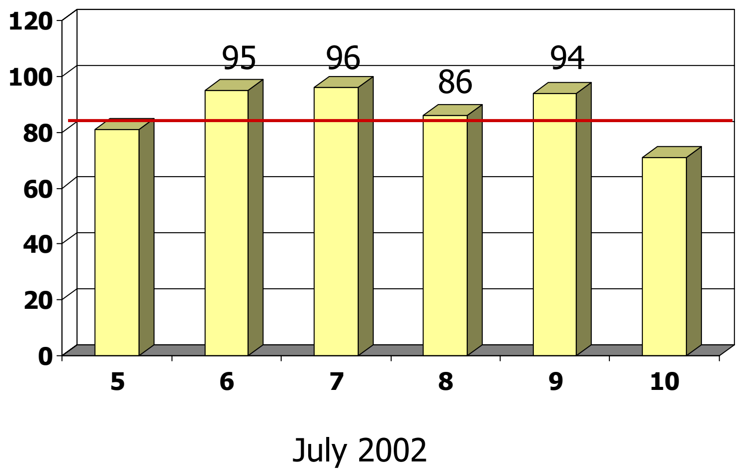
NASHVILLE: JULY 4-7



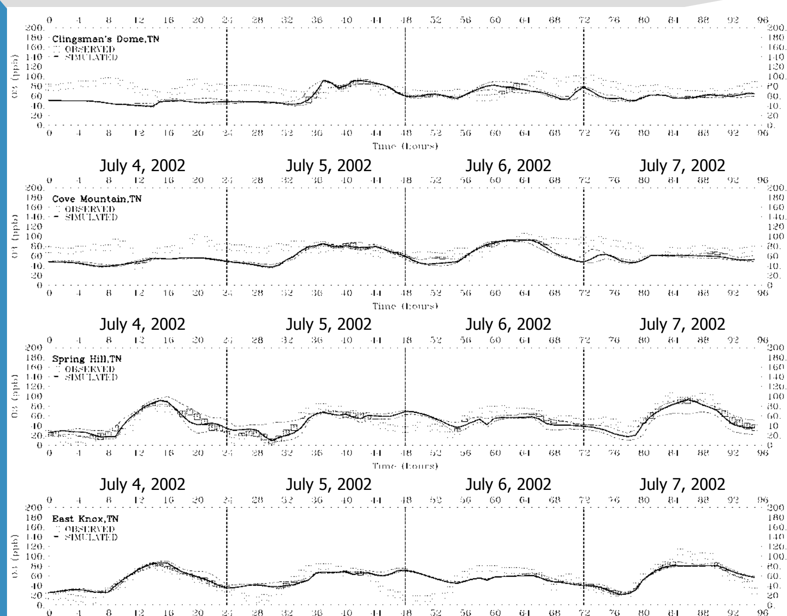
NASHVILLE: JULY 7-10



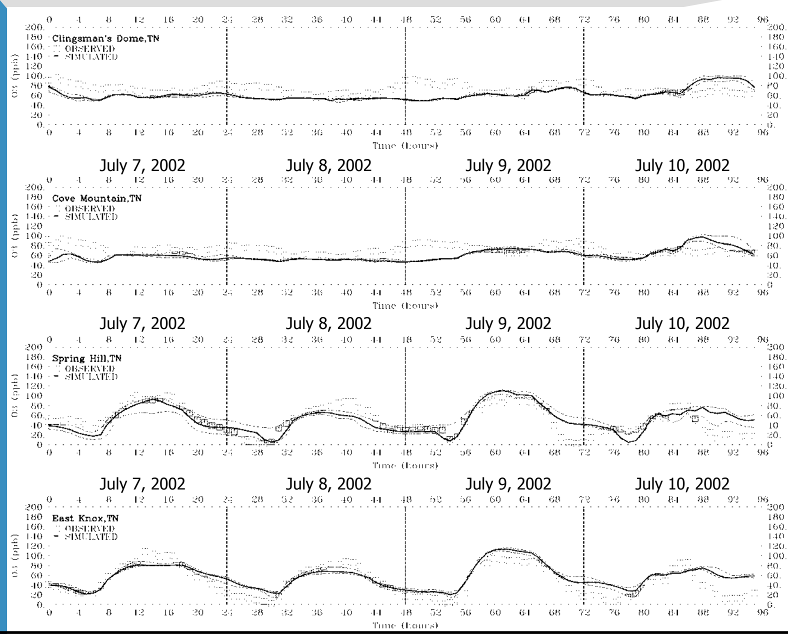
MAXIMUM 8-HOUR OZONE (PPB): KNOXVILLE/GSM AREA



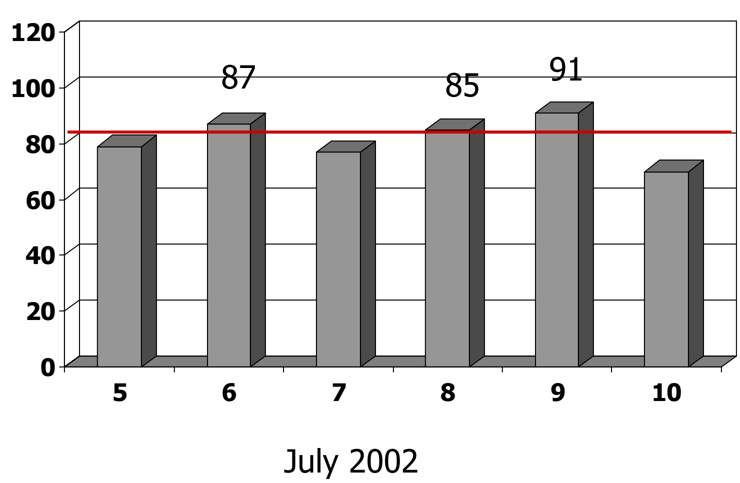
KNOXVILLE: JULY 4-7



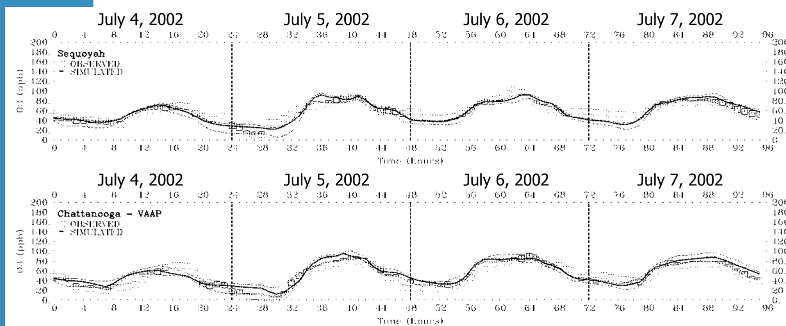
KNOXVILLE: JULY 7-10



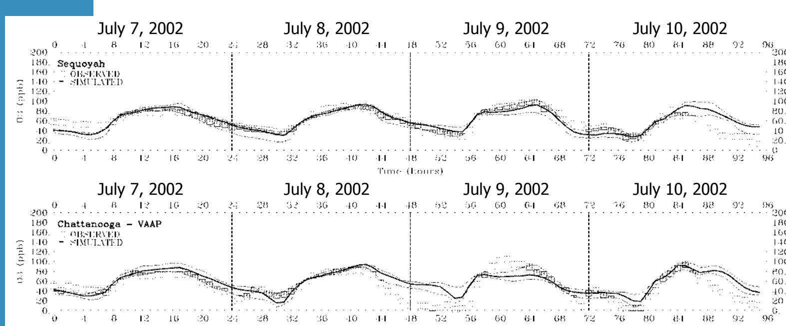
MAXIMUM 8-HOUR OZONE (PPB): CHATTANOOGA



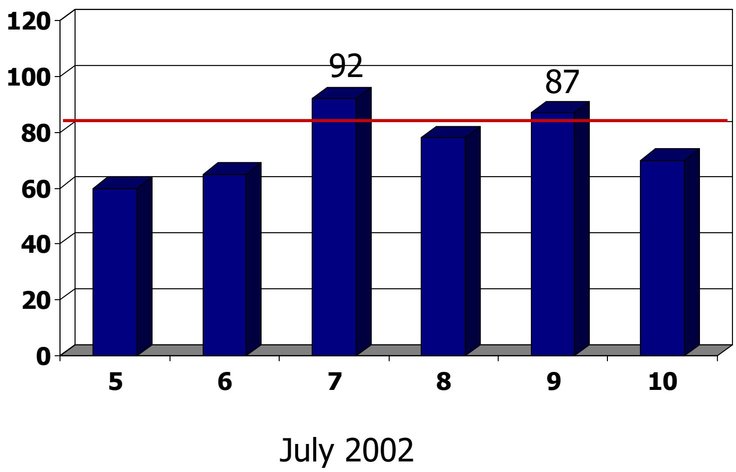
CHATTANOOGA: JULY 4-7



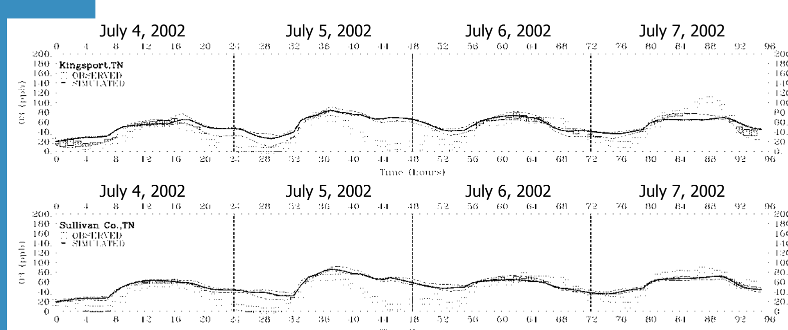
CHATTANOOGA: JULY 7-10



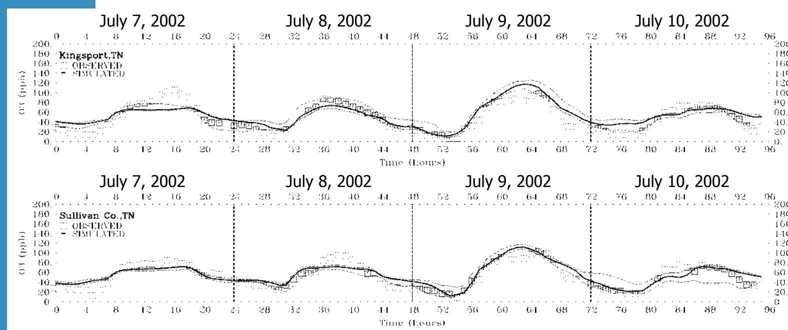
MAXIMUM 8-HOUR OZONE (PPB): TRI-CITIES AREA



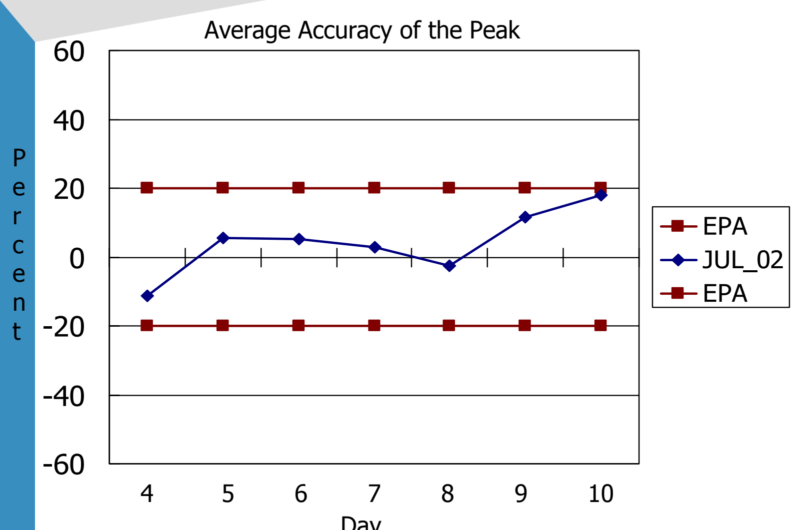
TRI-CITIES: JULY 4-7



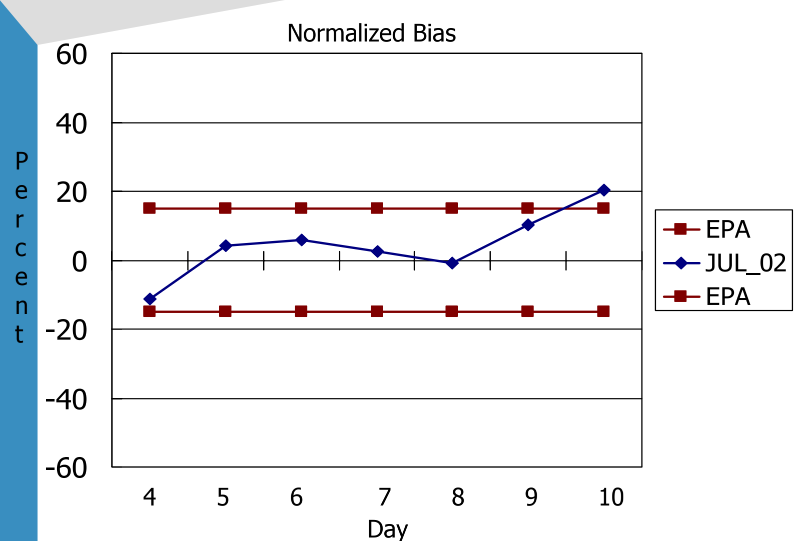
TRI-CITIES: JULY 7-10



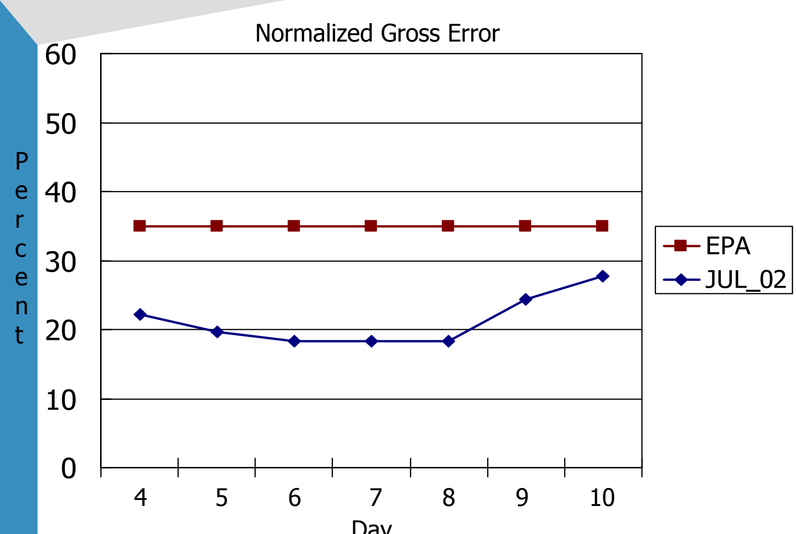
UAM-V SIMULATION RESULTS FOR JULY 2002: GRID 3



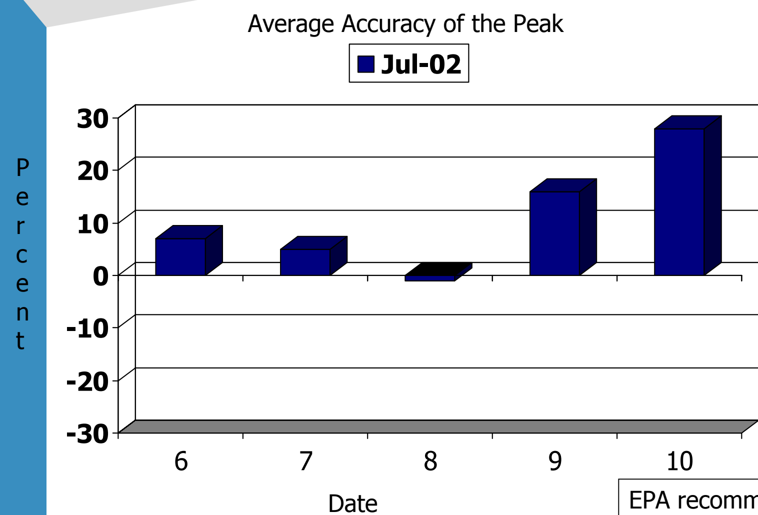
UAM-V SIMULATION RESULTS FOR JULY 2002: GRID 3



UAM-V SIMULATION RESULTS FOR JULY 2002: GRID 3



BASE-CASE MODEL PERFORMANCE FOR 8-HR OZONE: GRID 3



EPA recommended range is ±20%

Animation of July 2002 Episode Base Case

SUMMARY OF MODEL PERFORMANCE FOR ALL THREE EPISODES

- 8-hour stats for all sites in TN, AR, and MS are within the EPA recommended ranges
- Adding the July 2002 episode slightly improves the combined 8-hour stats

KEY ADVISOR METRICS

- Simulated 8-hour maximum ozone concentration
  - for selected domain, subregion, or monitoring site
  - [ppb]
- 8-hour ozone exceedance exposure
  - measure of the "excess" concentration and number of grid cell hours greater than 85 ppb
  - for selected domain or subregion
  - [ppb·grid cell·hours]

KEY ADVISOR METRICS

- Estimated design value (EDV)

  EDV= RRF·DV

  – RRF is the ratio of future-year scenario to base-year 8-hour ozone concentration in the vicinity of a monitoring site location
  – DV is observation-based, current-year design value
  – for selected monitoring site
  – [ppb]

EPA attainment test requires EDV to be ≤ 84 ppb

WHAT IS THE "CURRENT" YEAR?

August/September 1999 Simulation Period

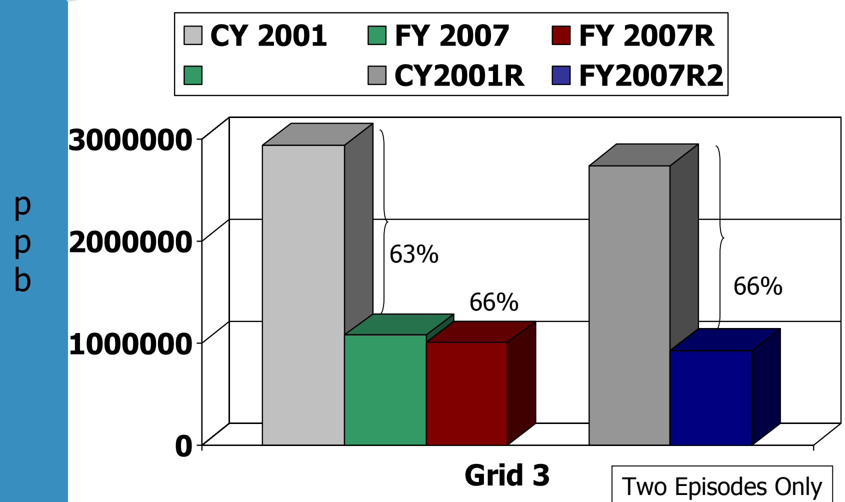
1999 Base Year → 2001 Current Year → 2007 Future Year

June 2001 Simulation Period

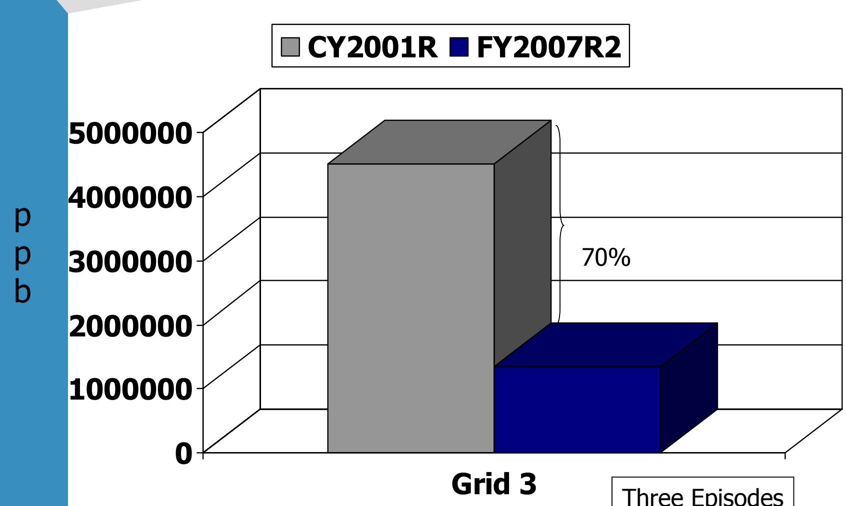
2001 Base Year → 2007 Future Year

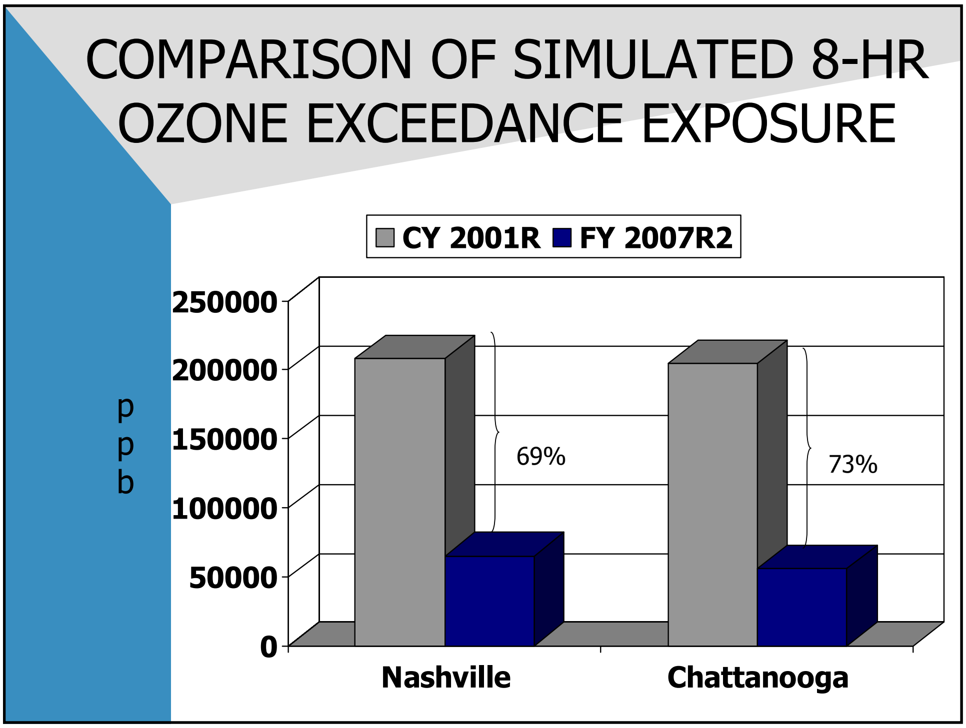
Both episodes use the same projection period

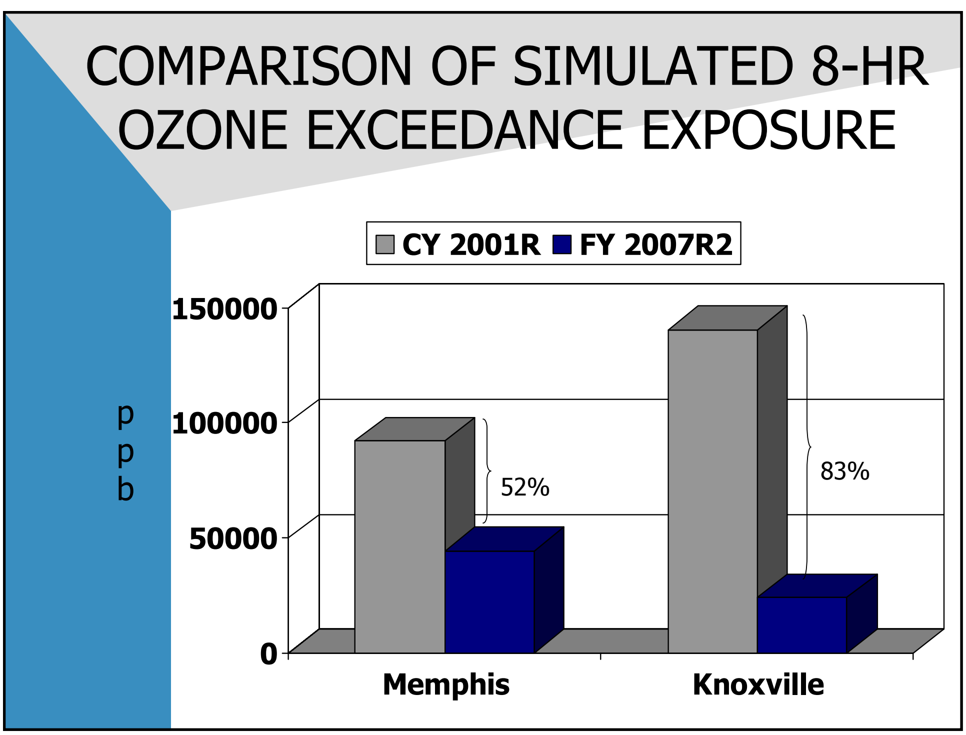
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



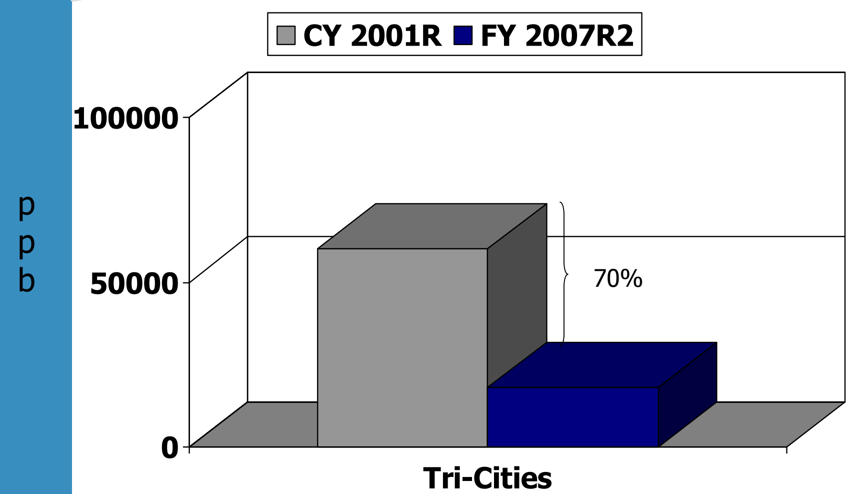
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



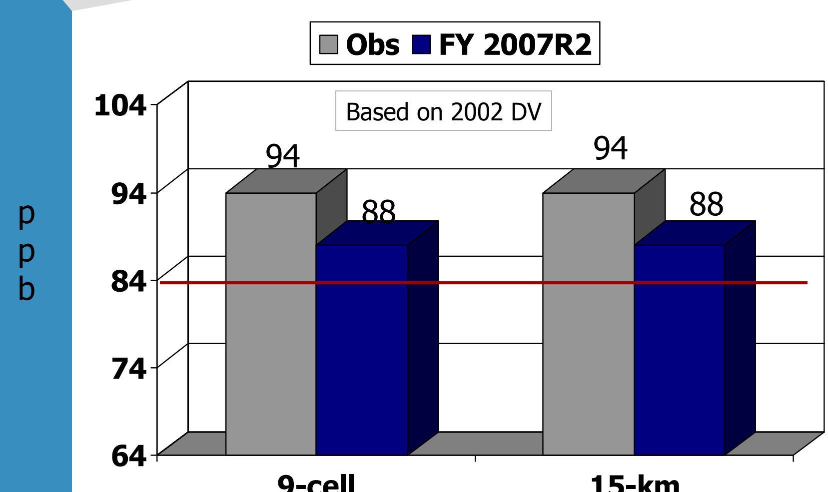

COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE
CY 2001R
FY 2007R2
ppb
250000
200000
150000
100000
50000
0
69%
73%
Nashville
Chattanooga


COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE
CY 2001R
FY 2007R2
ppb
150000
100000
50000
0
52%
83%
Memphis
Knoxville

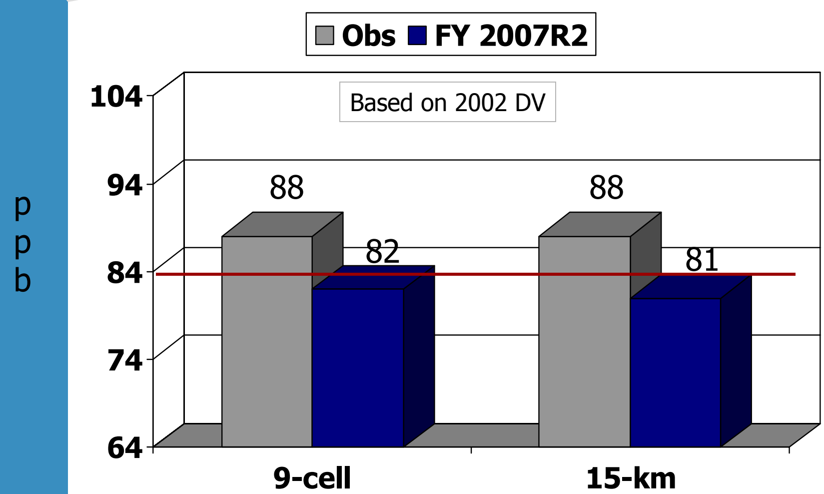
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



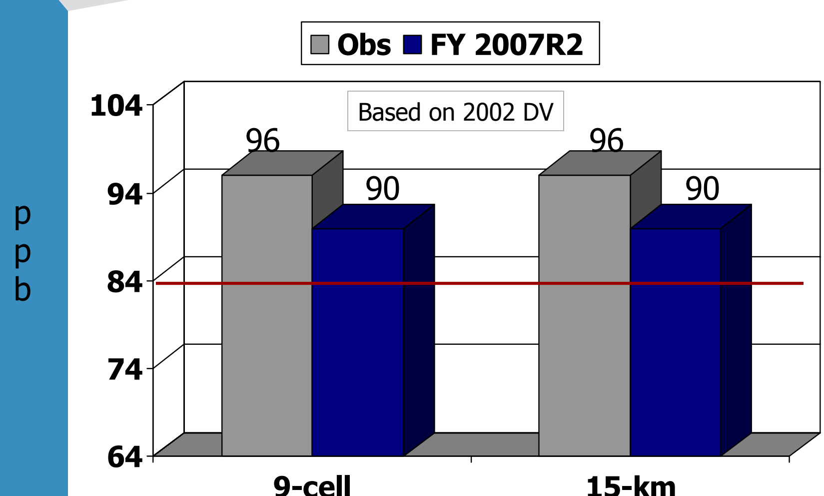
ESTIMATED DESIGN VALUE (EDV): MEMPHIS AREA



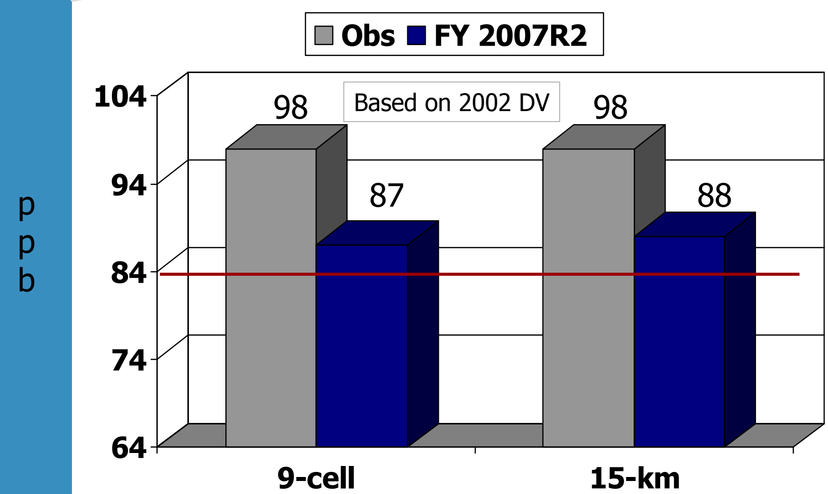
ESTIMATED DESIGN VALUE (EDV): NASHVILLE AREA



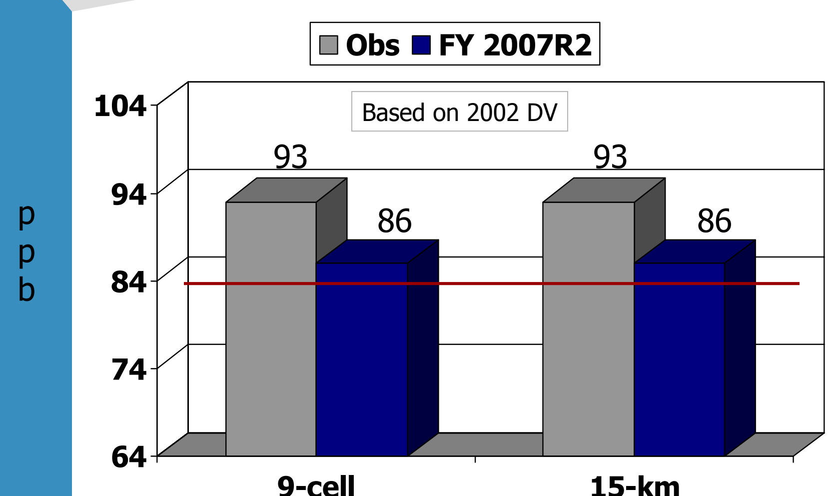
ESTIMATED DESIGN VALUE (EDV): KNOXVILLE AREA



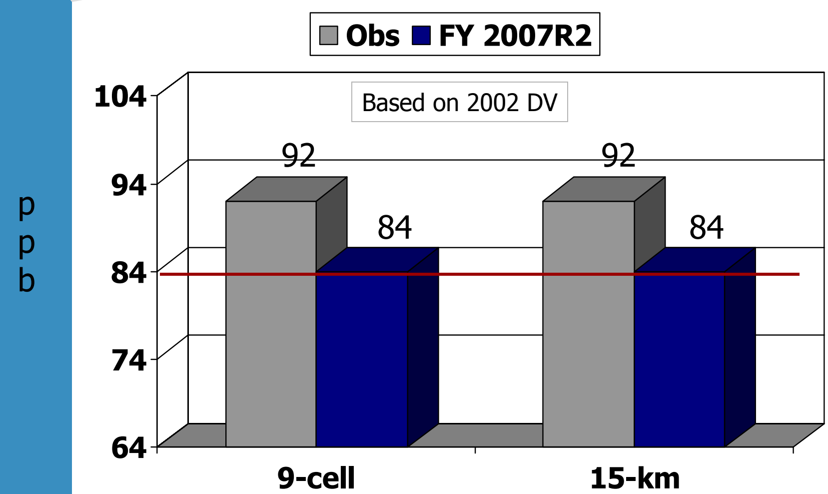
ESTIMATED DESIGN VALUE (EDV): GSM AREA



ESTIMATED DESIGN VALUE (EDV): CHATTANOOGA AREA



ESTIMATED DESIGN VALUE (EDV): TRI-CITIES AREA



REVISED FUTURE-YEAR BASELINE RESULTS WITH THREE EPISODES

- Compared to the prior baseline, 8-hour ozone exceedance exposure is lower than that for the current year by similar percentage amounts for all areas (except Tri-Cities)
- EDVs for 2007 are
  - about the same as for the prior 2007 baseline for Memphis, Knoxville, Chattanooga
  - lower for the Nashville, Tri-Cities, and GSM areas

DISCUSSION OF REVISED FUTURE-YEAR BASELINE RESULTS

- Additional high ozone days for the Tri-Cities area add to the robustness of the results and lower the EDVs
- Additional met conditions for Nashville change the EDV results slightly
- More days with similar met conditions for the other areas support the prior results
- Lower EDVs for the GSM area may be due to emissions changes or somewhat different source receptor relationships contained with the new episode

EMISSION REDUCTION SCENARIO AS-3: "EAC MEASURES"

- Simulation conducted to assess the effects of emission reductions from selected measures included in all EAC areas from:
  - Area sources
  - Non-road sources
  - On-road mobile sources
  - Point sources

POTENTIAL EAC MEASURES

- Area-source measures
  - Open burning ban – residential garbage
  - Open burning ban – yard waste
  - Open burning ban – land clearing
  - Lower gasoline RVP (7.8 to 7.0)
  - Lower gasoline RVP (9.0 to 7.8)
  - Stage I vapor recovery
  - Stage II vapor recovery
  - Ozone action day measures

POTENTIAL EAC MEASURES

- Non-road source measures
  - Construction equipment (X% new)
  - Airport vehicles (Y% new)

POTENTIAL EAC MEASURES

- On-road source measures
  - Inspection/maintenance (OBD only)
  - Intelligent transportation systems
  - Lower interstate truck speeds 10 mph
  - Truck stop electrification (X% of sites)
  - Cetane added to diesel
  - Anti-idling restrictions
  - Transit (increase bus ridership Y%)
  - Voluntary control measures
  - Smoking vehicle ban
  - HOV lane expansion
  - Signal synchronization
  - Low emission fleets
  - New rail service

POTENTIAL EAC MEASURES

- Point source measures
  - NOx RACT rule for sources greater than 50 tpy

MEMPHIS EAC SELECTED MEASURES (AS-3)

- Area-source measures
  - Open burning ban – residential garbage
  - Open burning ban – yard waste
  - Open burning ban – land clearing
  - Stage I vapor recovery
  - Ozone action day

MEMPHIS EAC SELECTED MEASURES (AS-3) (concluded)

- Onroad mobile measures
  - Inspection/maintenance (OBD only)
  - Intelligent transportation systems
  - Lower interstate truck speeds 10 mph
  - Truck stop electrification (10% of sites)
  - Anti-idling restrictions
  - Voluntary control measures
- Point source measures
  - NOx RACT on selected sources

DESOTO COUNTY SELECTED MEASURES (AS-3)

- No measures included in AS-3 scenario

CRITTENDEN COUNTY SELECTED MEASURES (AS-3)

- Area source measures
  - Open burning ban (garbage/yard waste)
  - Lower RVP (7.8 to 7.0)
  - Stage I vapor recovery
  - Ozone Action day measures
- Nonroad measures
  - New construction equipment
  - New airport service vehicles
- Onroad mobile measures
  - Lower interstate truck speeds 10 mph
  - Truck stop electrification (10% of sites)
  - Anti-idling restrictions
  - Cetane additive to diesel

NASHVILLE EAC SELECTED MEASURES (AS-3)

- Area-source measures
  - Open burning ban – construction/land clearing
  - AQAD measures

NASHVILLE EAC SELECTED MEASURES (AS-3) (concluded)

- On-road mobile measures
  - Roadside assistance program
  - Transit (increase bus ridership)
  - Trip reduction plans
  - Rideshare programs
  - HOV lane expansion
  - Signal synchronization
  - New greenways/bikeways
  - Reduce school bus idling
  - New rail service
  - Land use controls to reduce VMT

KNOXVILLE EAC SELECTED MEASURES (AS-3)

- Area-source measures
  - Open burning ban – residential garbage
  - Open burning ban – yard waste
  - Open burning ban – land clearing
  - Lower gasoline RVP (9.0 to 7.8)
  - Ozone action day measures
- Non-road
  - Construction equipment (14% new)

KNOXVILLE EAC SELECTED MEASURES (AS-3) (concluded)

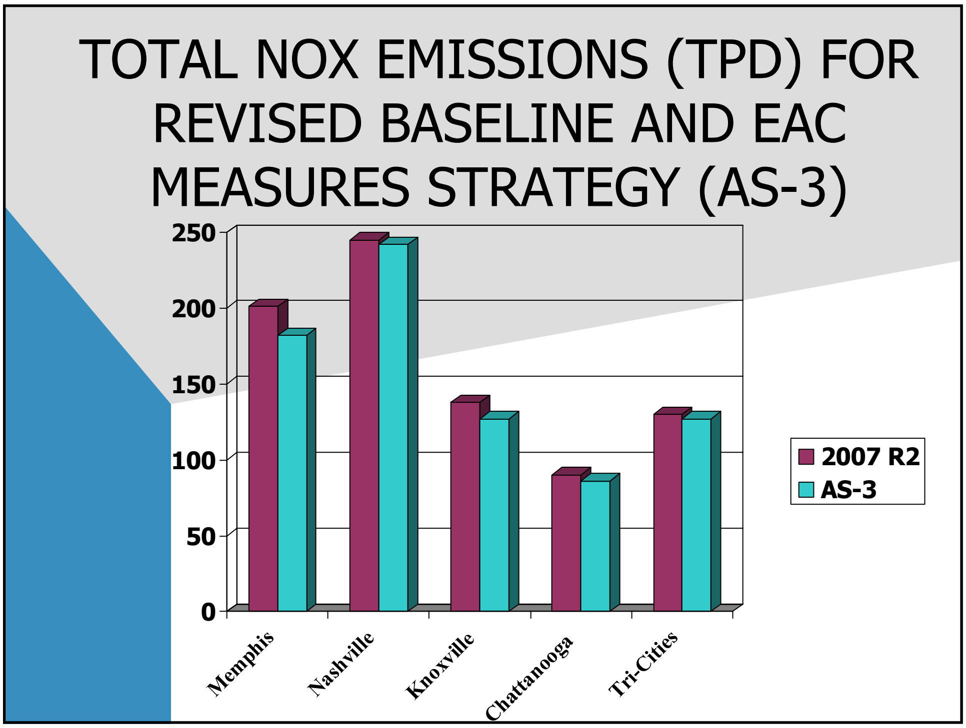
- On-road mobile measures
  - Truck stop electrification (30% of sites)
  - Cetane added to diesel
  - Transit (increase bus ridership 5%) (Knox Co. only)
  - Trip reduction programs (Knox and Blount)
  - Traffic flow improvements (Knox Co. only)
- Point-source measures
  - NOx RACT on selected sources

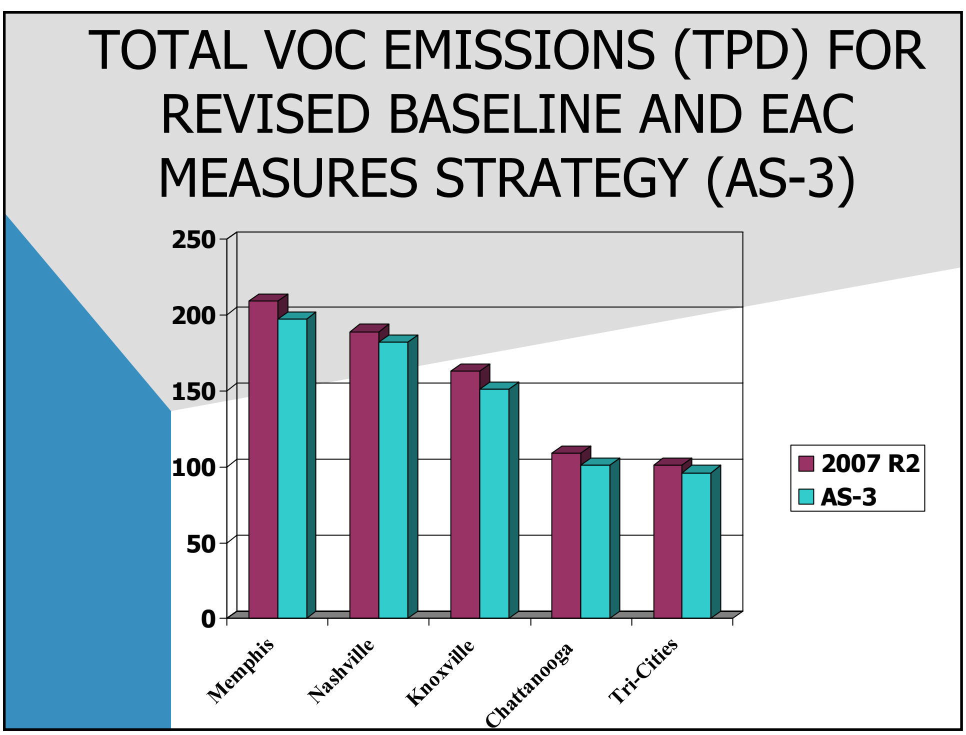
CHATTANOOGA EAC SELECTED MEASURES (AS-3)

- Area-source measures
  - Open burning ban – residential garbage
  - Open burning ban – yard waste
  - Open burning ban – land clearing
  - Stage I vapor recovery
  - Ozone Action Day measures
- Non-road measures
  - Construction equipment (10% new)
  - New airport vehicles (10% new)

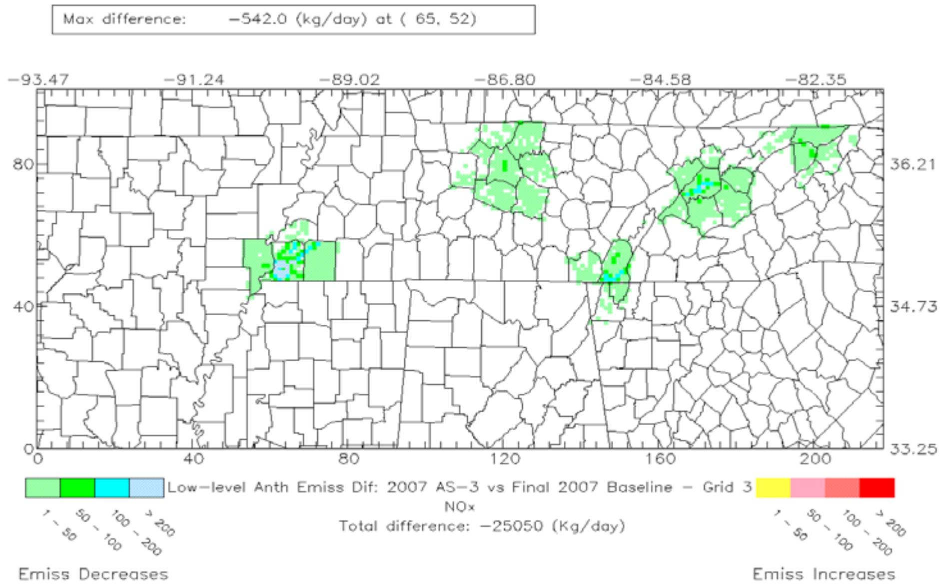
CHATTANOOGA EAC SELECTED MEASURES (AS-3) (concluded)

- On-road mobile measures
  - Lower interstate truck speeds 10 mph (Hamilton County only)
  - Cetane added to diesel
  - Anti-idling restrictions
  - Transit (increase bus ridership 10%)

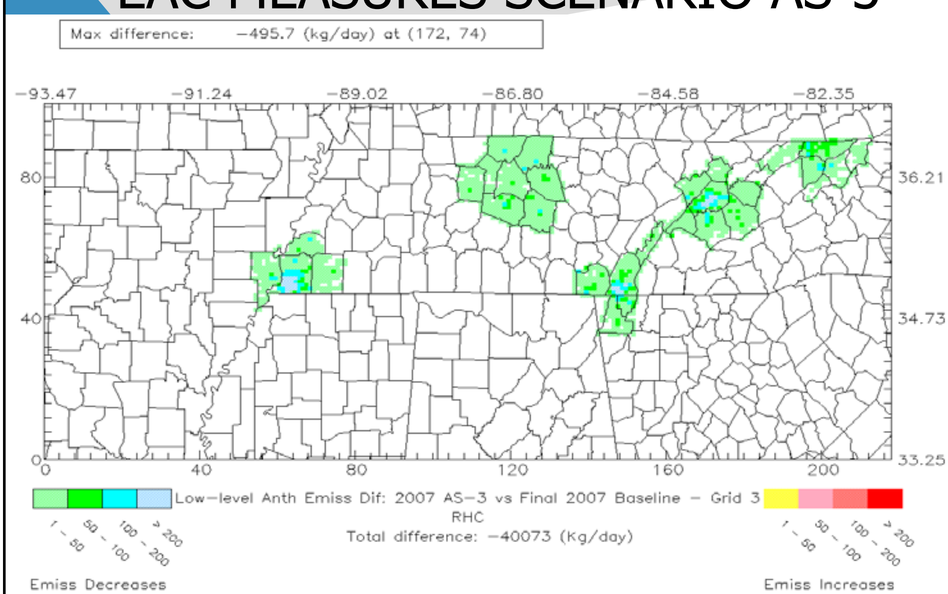

TOTAL NOX EMISSIONS (TPD) FOR REVISED BASELINE AND EAC MEASURES STRATEGY (AS-3)
250
200
150
100
50
0
Memphis
Nashville
Knoxville
Chattanooga
Tri-Cities
2007 R2
AS-3


TOTAL VOC EMISSIONS (TPD) FOR REVISED BASELINE AND EAC MEASURES STRATEGY (AS-3)
250
200
150
100
50
0
Memphis
Nashville
Knoxville
Chattanooga
Tri-Cities
2007 R2
AS-3

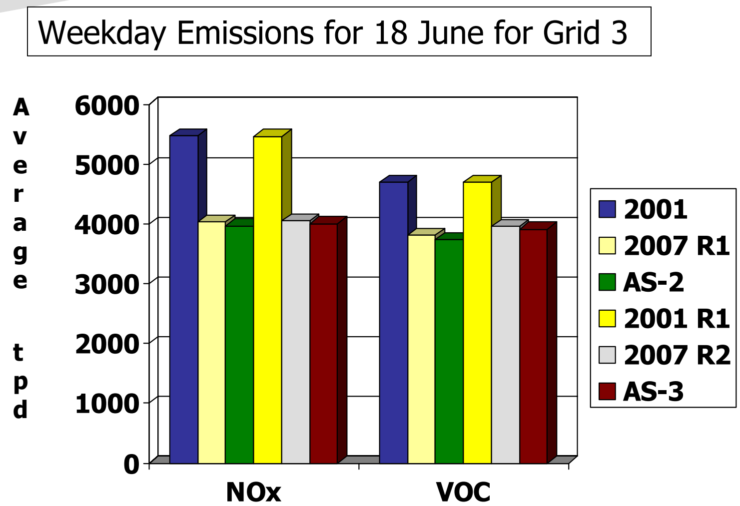
LOW-LEVEL NOX REDUCTIONS FOR EAC MEASURES SCENARIO AS-3



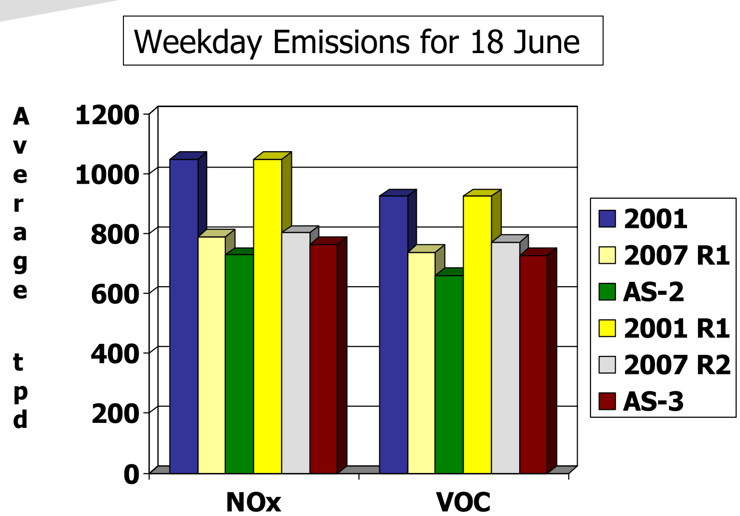
LOW-LEVEL VOC REDUCTIONS FOR EAC MEASURES SCENARIO AS-3



COMPARISON OF NO_x AND VOC EMISSIONS FOR GRID 3

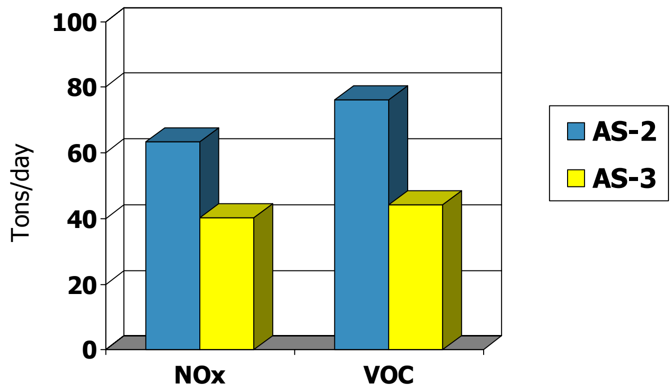


COMPARISON OF NO_x AND VOC EMISSIONS FOR EAC AREAS

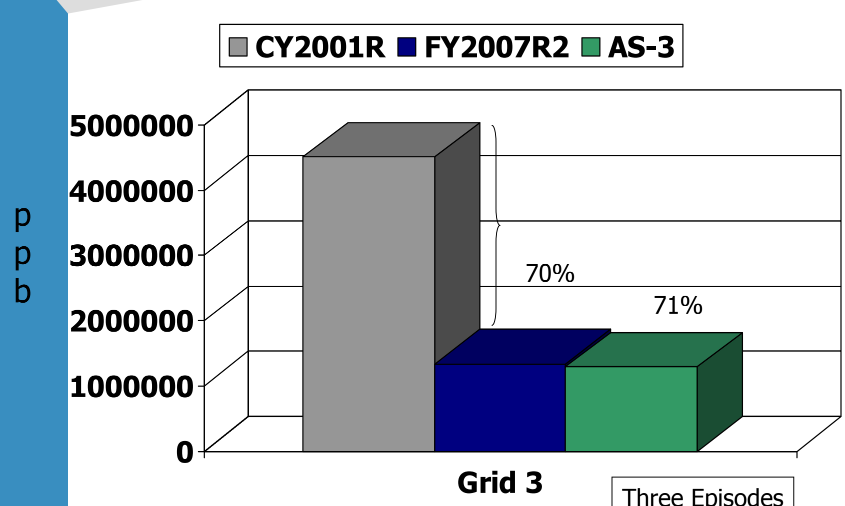


NOX AND VOC EMISSION REDUCTIONS FOR ALL EAC AREAS: AS-2 AND AS-3 STRATEGIES

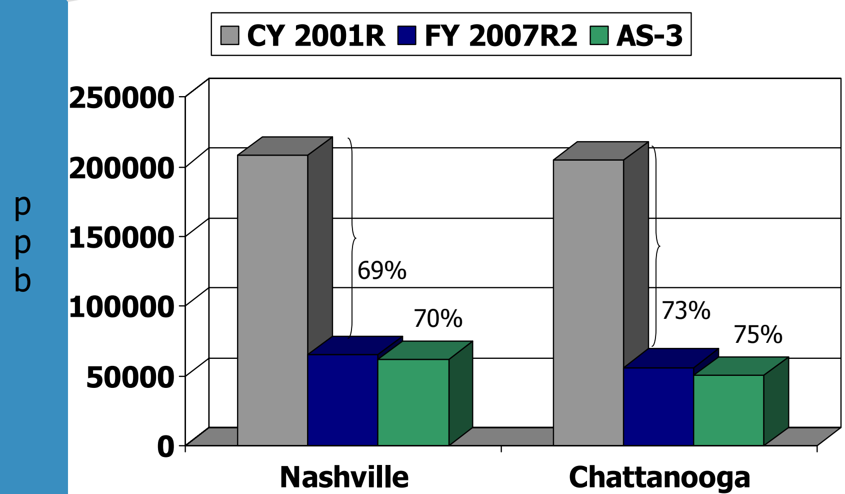
Emission reductions for 18 June episode day



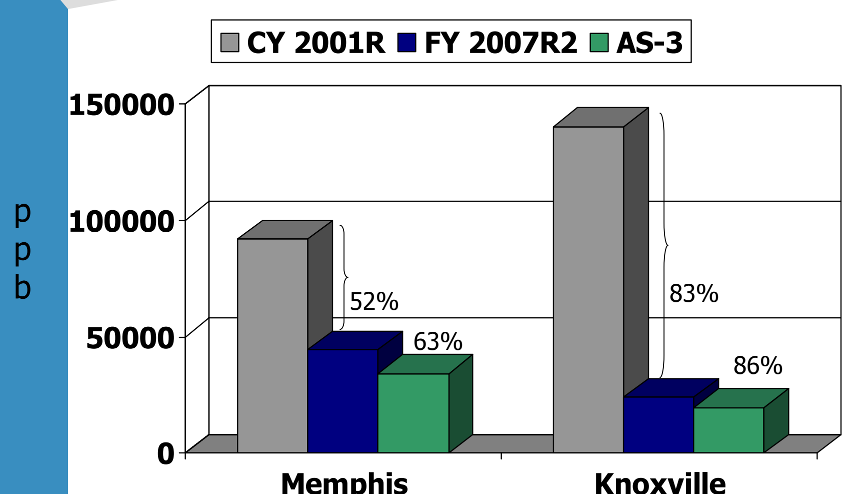
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



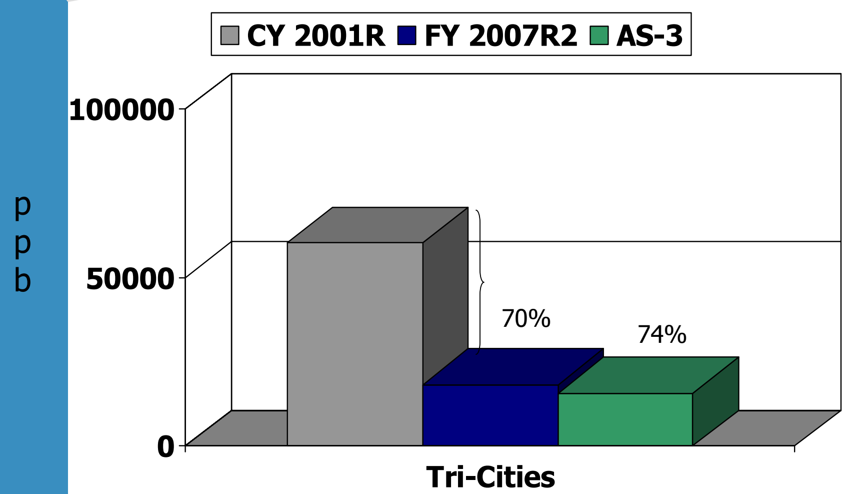
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



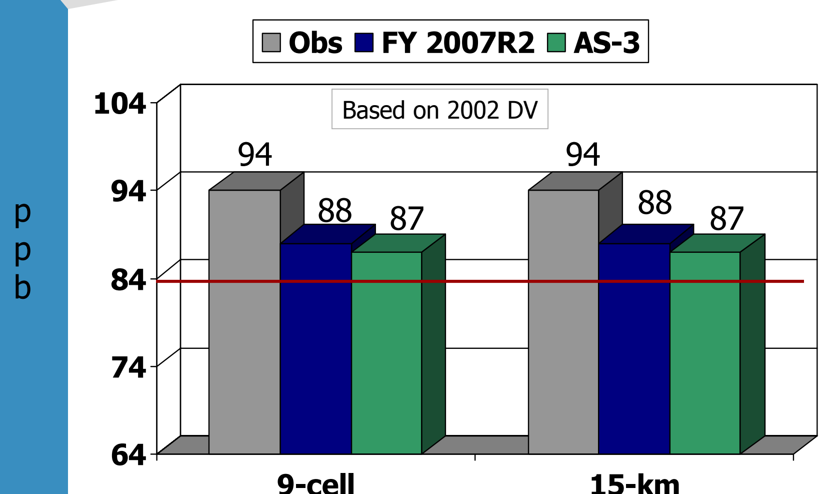
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



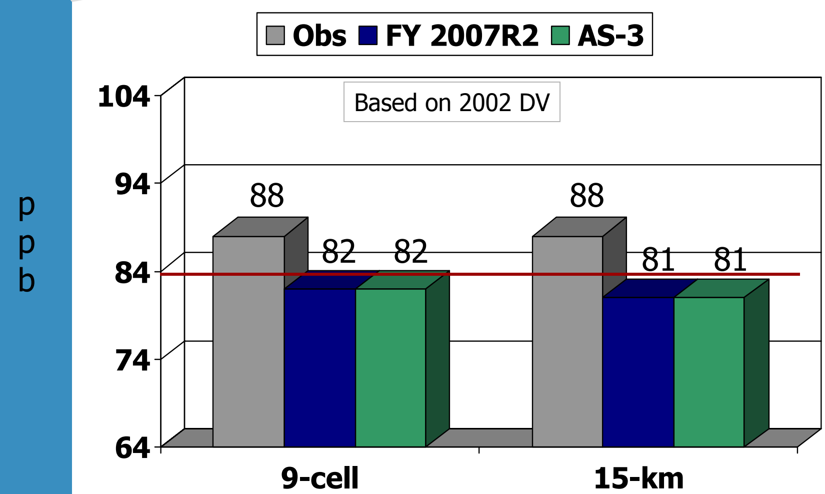
COMPARISON OF SIMULATED 8-HR OZONE EXCEEDANCE EXPOSURE



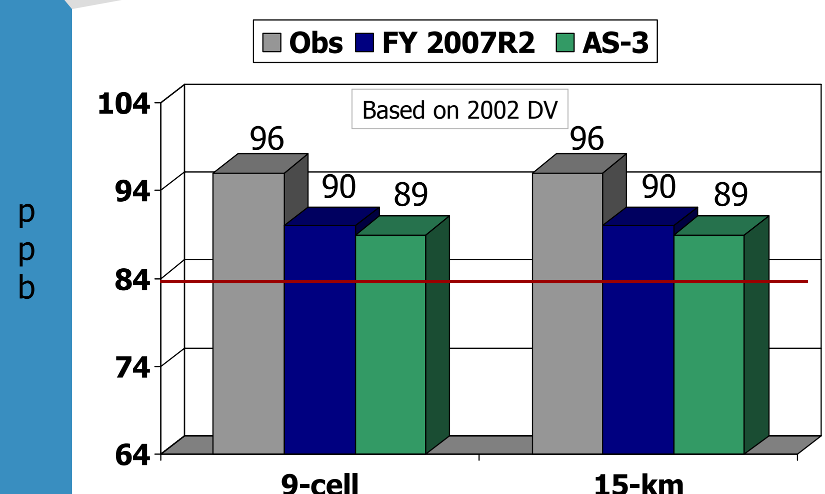
ESTIMATED DESIGN VALUE (EDV): MEMPHIS AREA

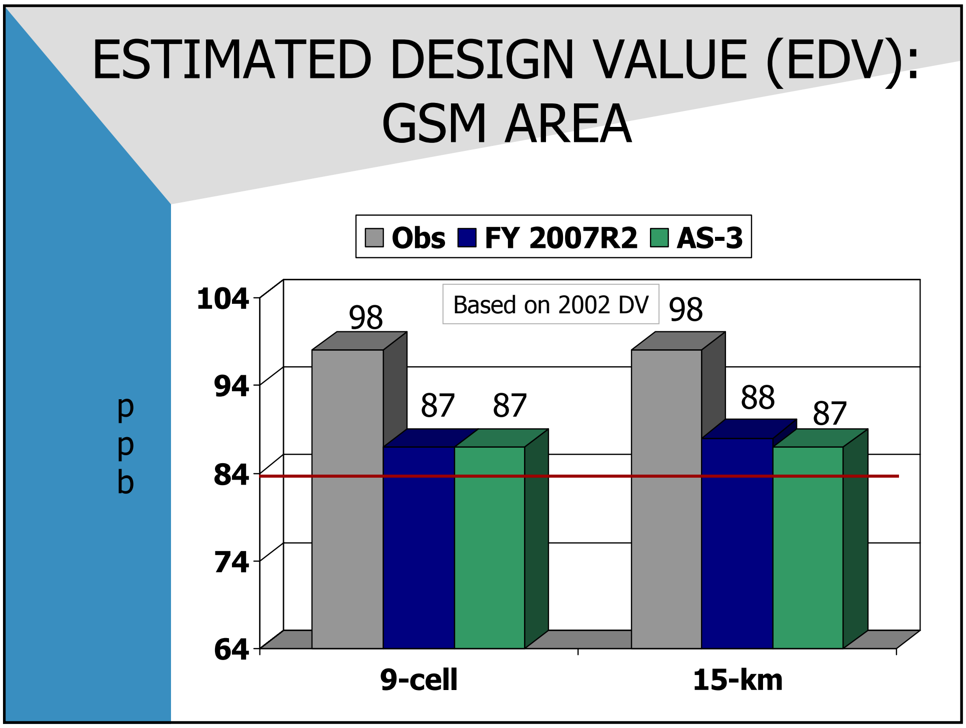


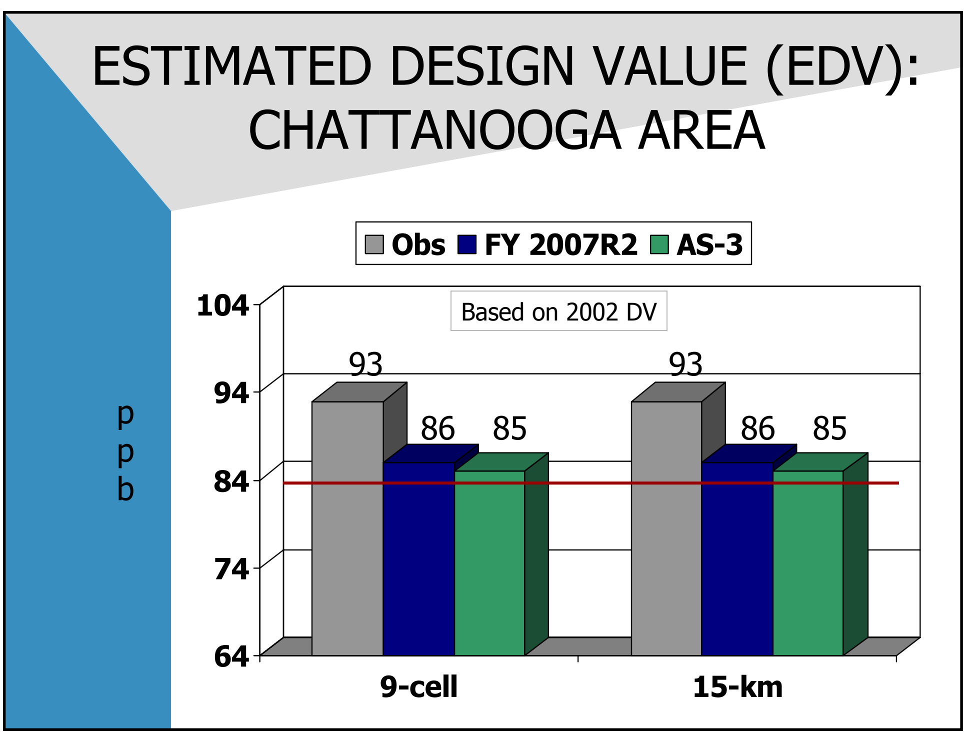
ESTIMATED DESIGN VALUE (EDV): NASHVILLE AREA



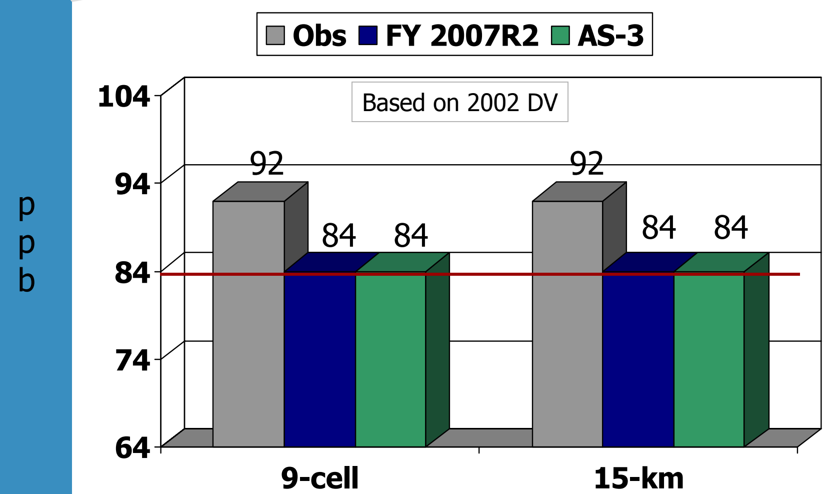
ESTIMATED DESIGN VALUE (EDV): KNOXVILLE AREA



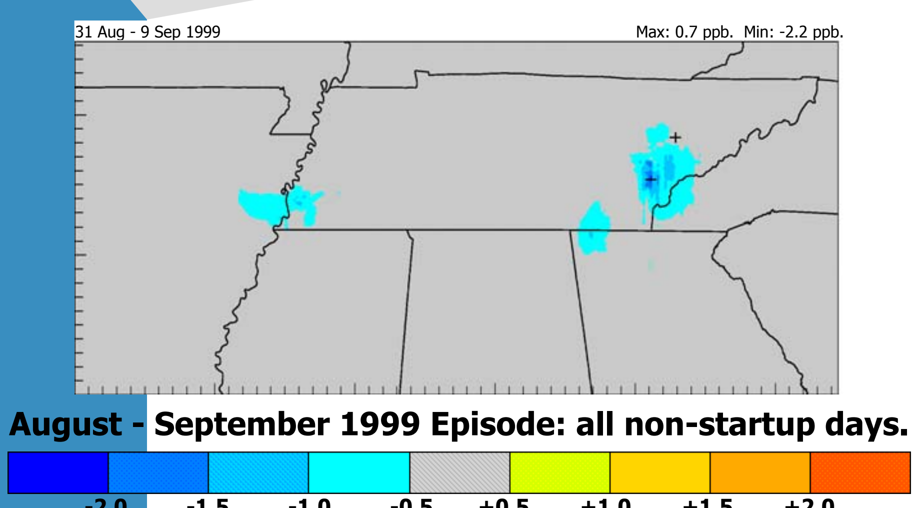

ESTIMATED DESIGN VALUE (EDV): GSM AREA
Obs
FY 2007R2
AS-3
Based on 2002 DV
104
94
84
74
64
ppb
98
87
87
98
88
87
9-cell
15-km


ESTIMATED DESIGN VALUE (EDV): CHATTANOOGA AREA
Obs
FY 2007R2
AS-3
Based on 2002 DV
104
94
84
74
64
ppb
93
86
85
93
86
85
9-cell
15-km

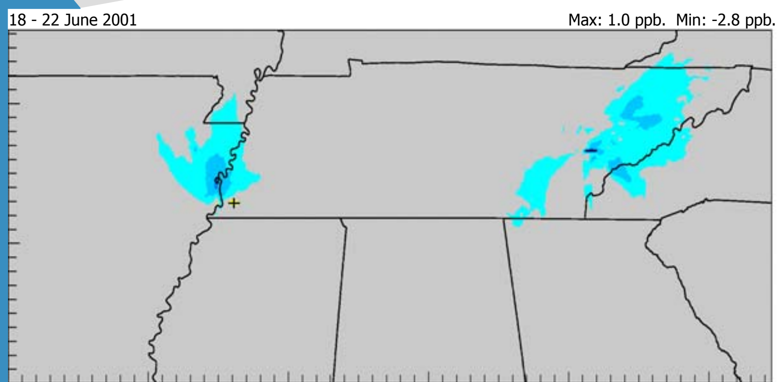
ESTIMATED DESIGN VALUE (EDV): TRI-CITIES AREA



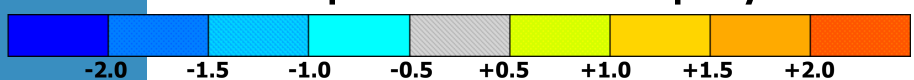
AVERAGE OF MAX DIFFERENCES AS3 - 2007 BASELINE



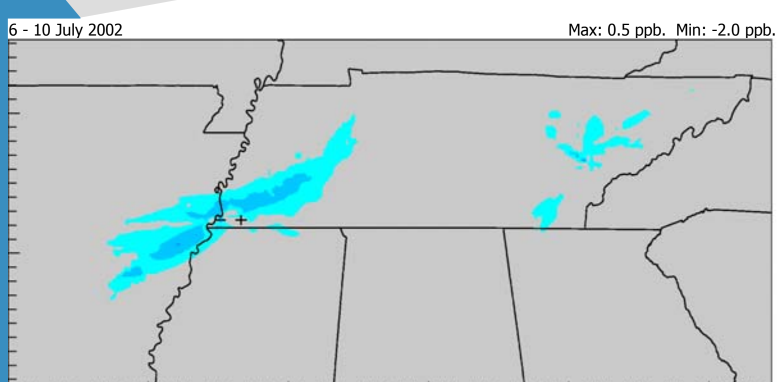
AVERAGE OF MAX DIFFERENCES
AS3 - 2007 BASELINE



June 2001 Episode: all non-startup days.



AVERAGE OF MAX DIFFERENCES
AS3 - 2007 BASELINE



July 2002 Episode: all non-startup days.

SUMMARY OF AS-3 RESULTS

- Compared to the latest, revised 2007 baseline, 8-hour ozone exceedance exposure is lower by
  - 22% for Memphis EAC area
  - 5% for Nashville EAC area
  - 19% for Knoxville EAC area
  - 10% for Chattanooga EAC area
  - 14% for Tri-Cities EAC area

SUMMARY OF AS-3 RESULTS (CONTINUED)

- EDVs are lower by 1 ppb for the Memphis, Knoxville and Chattanooga areas and unchanged for the Nashville and Tri-Cities areas (varies a little with 15-km approach)
- Values are
  - 87 ppb for Memphis EAC area
  - 82 ppb for Nashville EAC area
  - 89 ppb for Knoxville EAC area
  - 85 ppb for Chattanooga EAC area
  - 84 ppb for Tri-Cities EAC area

SUMMARY OF AS-3 RESULTS (CONCLUDED)

- AS-3 emission reductions contribute to ozone reductions in downwind areas
- No other potential non-attainment areas are affected by the AS-3 reductions in the areas of interest

ATTAINMENT DEMONSTRATION ANALYSIS

- Attainment demonstration consists of
  - Attainment test
  - Screening test
  - Additional weight of evidence

OVERVIEW OF THE MODELED ATTAINMENT TEST: SITE-SPECIFIC

- Determine the 8-hour ozone design value for each monitoring site (3-year average of the annual 4th highest 8-hour ozone concentration)
- Use UAM-V results to calculate a relative reduction factor (RRF) for each monitoring site - defined as the ratio of the future- to base-year 8-hour maximum ozone concentration in the "vicinity" of the site
- Multiply the current-year design value by the RRF to estimate the future design value
- If future site-specific design values are $\leq$ 84 ppb, the test is passed

OVERVIEW OF THE SCREENING TEST

- Examine the modeling results and determine whether there are <u>areas in the domain</u> where the simulated concentrations are <u>consistently</u> greater than any in the vicinity of a monitoring site using the following definitions:
  - *Area in the domain*: array of cells centered on grid cell where simulated concentrations are <u>consistently</u> greater than any near a monitored location
  - *Consistently*: simulated 8-hour maximum concentrations are more than 5% higher than any near a monitor on 50% or more of the simulation days

OVERVIEW OF THE SCREENING TEST (CONCLUDED)

- Use UAM-V results to calculate a RRF for each such unmonitored area
- Multiply the maximum current-year design value for the nonattainment area by the RRF (for the unmonitored location) to estimate the future design value for the unmonitored location of interest
- If the estimated future design value for the unmonitored location is $\leq$ 84 ppb, the test is passed

WEIGHT OF EVIDENCE

- Possible elements include
  - EPA recommended additional metrics (related to change in exceedance hours and exposure)
  - Emissions trends
  - Observed ozone (and design value) trends; design value representativeness
  - Uncertainty in the modeling associated with
    - Modeling system (including input) errors and approximations (“noise”)
    - Episode representativeness
    - Model performance issues
    - Emissions projections

WEIGHT OF EVIDENCE (CONTINUED)

- Possible elements include
  - Uncertainty attributed to application of the attainment and screening test procedures
    - Definition of vicinity/Site-specific vs. grid based RRFs
    - Day selection (number and type of days, e.g., accounting for frequency of occurrence)
  - Transport assessment (e.g., using tagging results)

WEIGHT-OF-EVIDENCE CONSIDERATIONS FOR MEMPHIS

- Findings to date:
  - 8-hour exceedance exposure reduced by approximately 60%
  - 2007 EDV for AS-3 is 87 ppb
  - EDVs for 3 of 4 sites are well below 84 ppb
- Required and recommended analysis:
  - **Screening test** (apply for subset of domain surrounding Memphis EAC)- examine site-specific and grid based approaches
  - Calculate additional recommended metrics
  - Examine episode and **DV representativeness** and met adjusted 8-hour ozone trends (using CART results)
  - Examine effects of **modeling uncertainties**
  - Examine **alternative attainment test procedures**

WEIGHT-OF-EVIDENCE CONSIDERATIONS FOR NASHVILLE

- Findings to date:
  - 8-hour exceedance exposure reduced by approximately 70%
  - 2007 EDV for AS-3 is 82 ppb (81 if 15-km approach is used)
  - EDVs for all sites are below 84 ppb
- Required and recommended analysis:
  - Screening test (apply for subset of domain surrounding Nashville EAC)- examine site specific and grid based approaches
  - Calculate additional recommended metrics
  - Examine **episode and DV representativeness** and met adjusted 8-hour ozone trends (using CART results)
  - Examine effects of **modeling uncertainties (good performance)**
  - Examine **alternative attainment test procedures**

WEIGHT-OF-EVIDENCE CONSIDERATIONS FOR KNOXVILLE

- Findings to date:
  - 8-hour exceedance exposure reduced by approximately 86%
  - 2007 EDV for AS-3 is 89 ppb
- Required and recommended analysis:
  - **Screening test** (apply for subset of domain surrounding Knoxville EAC)- examine site-specific and grid based approaches
  - Calculate **additional recommended metrics**
  - Examine **episode and DV representativeness** and met adjusted 8-hour ozone trends (using CART results)
  - Examine effects of modeling uncertainties and **transport**
  - Examine alternative attainment test procedures

WEIGHT-OF-EVIDENCE CONSIDERATIONS FOR CHATTANOOGA

- Findings to date:
  - 8-hour exceedance exposure reduced by approximately 75%
  - 2007 EDV for AS-3 is 85 ppb
- Required and recommended analysis:
  - **Screening test** (apply for subset of domain surrounding Chattanooga EAC)- examine site-specific and grid based app.
  - Calculate **additional recommended metrics**
  - Examine episode and **DV representativeness** and met adjusted 8-hour ozone trends (using CART results)
  - Examine effects of **modeling uncertainties (v. good performance) and transport**
  - Examine alternative attainment test procedures

WEIGHT-OF-EVIDENCE CONSIDERATIONS FOR TRI-CITIES

- Findings to date:
  - 8-hour exceedance exposure reduced by approximately 74%
  - 2007 EDV for AS-3 is 84 ppb
- Required and recommended analysis:
  - **Screening test** (apply for subset of domain surrounding Tri-Cities EAC)- examine site specific and grid based approaches
  - Calculate **additional recommended metrics**
  - Examine **design value and episode representativeness**
  - Examine effects of **modeling uncertainties (some model performance issues)**
  - Examine alternative attainment test procedures

2007 ATMOS/EAC MODELING NEXT STEPS (FOR DISCUSSION)

- Refine attainment strategies, prepare emissions and conduct FINAL EAC <u>attainment-strategy</u> simulation(s) for 2007
  - AS-4 refined/revised local measures (by 2/27)
  - AS-5 state-wide measures (also by 2/27)
  - Complete final runs by (3/8)
- Complete preliminary attainment demo analysis/TSD (for submittal by 3/31)
  - OPTM for July 2002 (NC, VA/WV, KY, GA(Atl))
  - Documentation of inputs etc. (draft by 3/1)
  - Attainment test application (max values, RRFs, alternatives) (draft by 3/15; comments by 3/22; revised by 3/29)

2007 ATMOS/EAC MODELING NEXT STEPS (FOR DISCUSSION)

- Prepare 2012 emission inventory, conduct 2012 baseline simulation and assess "maintenance"
  - Grown from final 2007 EAC attainment strategy; IAQR measures should be accommodated in some manner
  - Inventory completed by 3/8; run by 3/15
- Communications
  - Conference calls (week of 3/15; week of 3/22)
  - Final meeting for EAC phase of ATMOS? (Apr/May)